University of Alberta

Feasibility Study of a Commercial Shipping Route through the Canadian Arctic

by

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A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of Master of Science

in

Engineering Management

Department of Mechanical Engineering

Edmonton, Alberta

Spring 2005

0-494-08151-1

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"If a Man will begin with certainties he shall end in doubts, but if he will be content to begin with doubts he will end in certainties."

Francis Bacon

Abstract

It was reported in the general press that global warming has resulted in the thawing of the Arctic seas and, hence, in a shorter trade route to Asia from North America. This present study using simulation techniques was conducted, to verify the feasibility of a commercial shipping venture if such an opportunity exists. A general purpose simulation language, VSLAM was used to check the trafficability. The economic performance was evaluated by estimating the required freight rate. For this purpose, a stochastic cost model was constructed, and a spreadsheet simulation experiment was conducted. Based on the required freight rate, it was found that the venture would be viable in the Asia-to-Canada trade route, even at an incremental capital requirement of 50%. The sensitivity of the "required freight rate" to various inputs was checked, and was found to be most sensitive to capital cost followed by, power demand in ice.

Acknowledgements

I would like to thank Dr. Peter Flynn, Professor and Poole Chair in Management for Engineers, for his encouragement in converting this work, which was initially submitted as a capstone project into a thesis. I would also like to express my thanks to Dr. Jozef Szymanski, Professor, School of Mining, for introducing me to the fascinating world of simulation analysis. My thanks go to Captain M.S. Nagarajan, General Manager (Operations), Fleet Management Limited, Hong Kong, for his valuable inputs pertaining to the costs of running a ship.

In addition, I thank my wife, Ambika, and son, Rohith, for coping up with my frustration while working with the enormous ice archives data.

Thank you to the Department of Mechanical Engineering for accepting me into the programme.

Contents

1 Introduction 1

1.1 Background 1

1.2 Methodology 2

2 Simulation of Ship's Transit through Canadian Arctic 4

2.1 Overview of Transit Simulation 4

2.2 Input Modeling 5
  2.2.1 Defining performance measure and input parameters 6
  2.2.2 Analysis of the physical system 7
    2.2.2.1 Meteorological variables 7
    2.2.2.2 Oceanographic variables 9
    2.2.2.3 Ice conditions 9
  2.2.3 Defining data source and range 12
    2.2.3.1 Data Source 12
    2.2.3.2 Selection of temporal range of data 13
    2.2.3.3 Selection of the spatial range and routes 15
  2.2.4 Correlation between ship's speed and ice conditions 18
  2.2.5 Developing the modeling framework 21
  2.2.6 Collection of historic ice data 23
  2.2.7 Digitization of historic ice data 24
  2.2.8 Curve fitting and transfer of input model to the system model 26

2.3 System modeling 33
  2.3.1 Defining the scenarios to be investigated 33
  2.3.2 Defining the relationships among the process variables 35
  2.3.3 Pre-modeling assumptions 37
  2.3.4 Creating a computer model: Network modeling 39
    2.3.4.1 Network description: The Arctic transport system 40
    2.3.4.2 Network description: The Panama Canal transport system 42

2.4 Output analysis of the transit model 43
  2.4.1 Simulation result: Monthly average transit speeds 43
  2.4.2 Simulation results: Round trips per year 44

2.5 Summary of transit simulation 47

3 Simulation of economic performance 49

3.1 Overview of Economic simulation 49

3.2 Input modelling: Assumptions and concepts 49
  3.2.1 Pre-modelling assumptions: Ship's specifications 50
  3.2.2 Cost estimation: An overview 51

3.3 Voyage costs 53

3.3.1 Voyage costs: Fuel 54
3.3.2 Voyage cost: Canal and ice-breaker dues 56
3.3.3 Voyage cost: Luboil 57

3.4 Operating costs 58
3.4.1 Operating cost: Technical management fees 59
3.4.2 Operating cost: Dry docking 60
3.4.3 Operational cost: Insurance premiums 61

3.5 Capital recovery cost 62

3.6 System modeling 63

3.7 Output analysis 66
3.7.1 Output analysis: RFR 66
3.7.2 Output analysis: Specific cost: 68

4 Conclusion 71

4.1 Summary: 71

4.2 The model's limitations and scope for further research 72

5 References 74

Appendix 1. Understanding ice EGG code and ice type nomenclature 78

Appendix 2. Map showing the selected Arctic routes 80

Appendix 3. Ice numeral calculation procedure and description of Canadian ice class ships. 81

Appendix 4. Passage plan for the coastal route and distances of legs 88

Appendix 5. Internodal distances and ice numeral quota 91

Appendix 6. Digitisation of ice data. A sample ice chart and corresponding spreadsheet model 92

Appendix 7. Ice numerals for CAC 3 ships 94

Appendix 8. Fitted distributions and global variable assignment for CAC3 ship. 10

Appendix 9. VSLAM network and statements for transit simulation................ 115

Appendix 10.Transit simulation results: Multiple summary statements........... 123

Appendix 11.Spread sheet model: Economic performance simulation. 131

Appendix 12. Reports: Economic performance simulation. 132

List of Tables

1. Distributions available in VSLAM 27
2. Ice numeral sample (Amundsen Gulf- 03 OCT; CAC3 ship) 29
3. Ice numeral sample (Amundsen Gulf - 01 APR; CAC3 ship) 30
4. A sample Peel Sound ice numeral (01 JUN; CAC3 ship) 31
5. Dimensions of Panamax bulk carrier 34
6. Dimensions of Panamax container ships 34
7. Distances between terminal ports 34
8. Monthly average speeds of a 20 Knots CAC3 ship through Canadian Arctic. 44
9. Round trips per year and earning potential of various ventures 46
10. Results of transit simulation 47
11. Ship's specifications 50
12. Specific fuel consumption: Marine two-stroke engines 54
13. Estimate of bunker prices 56
14. Estimation of Panama Canal charges 56
15. Correlation matrix for cost variables 65
16. Consolidated economic simulation results: RFR 67
17. Specific cost: Various Options 70

List of Figures

1. A sample Normal Distribution range 17-20 from fit results 29
2. A sample Beta Distribution range 17 -20 from fit results 29
3. A sample Normal Distribution range 17.5 to 19.5 from fit results 29
4. A sample BETA Distribution range 17.5 to 19.5 from fit results 29
5. A sample Normal Distribution from fit results 30
6. A sample P-P Graph from fit results 30
7. A Sample Q-Q Graph from fit results 30
8. A Sample Triangular distribution from fit results 31
9. Relationship between speed and ice numeral for an 11 knots ship 36
10. Relationship between speed and ice numeral for a 20 knots ship 36
11. Monthly average speed for 20 Knots CAC3 ship 44
12. Earning potential of various alternatives 45
13. Relationship between RFR and capital for Yokohama-to-St John's option ... 68
14. Comparison of specific costs 69

List of Nomenclature and abbreviations

1. AIRSS: Canadian Arctic Ice Regime Shipping System-See Transport Canada Publication, TP 12259E (23) for details.
2. Bunkers: Ship's fuel. Can be coal, heavy fuel oil, plutonium or natural gas.
3. Bunkering: Fuelling a ship often from barges. The process may take 7 men and up to 12 hrs in some cases and is carried out once in a month.
4. Barging charges. The cost of hiring a barge.
5. CHS: Canadian Hydrographic Service.
6. Charts: Maps used at sea showing depths of water, land contours and navigational hazards.
7. CRREL: US Army, Cold Regions Research and Engineering Laboratory.
8. CAC ships: Canadian Arctic class ships designated based on their ice strengthening. See Transport Canada Publication TP 12259E (23) for details.
9. Charterers: The party which hires or rents a ship.
10. Draught: The underwater depth of a ship from water line to keel.
11. Heavy Fuel Oil: A tar-like refinery residue (180 to 380cst viscosity) on which marine engines run and which is often adultered with industrial waste.
12. Knots: nautical miles per hour, a unit for expressing a ship's speed.
13. LFO: Low frequency Oscillations. Meteorologist's way of referring to slow multi-decadal changes in climate, snow/ice cover, etc.
14. Luboil: marine engineers' short form for Engine Lubricating Oils.
15. NOAA: National Oceanic and Atmospheric Administration. US Department of commerce.

16. NM: Nautical Mile. A means of measuring distance at sea 1NM=1.852 kilometres. It is also the approximate distance between one minute of arc of latitude.
17. @Risk: An Excel-based Simulation Addin. Trademark of Palisade Corporation.
18. RFR: Required freight rate obtained by dividing cost by cargo-carrying capacity.
19. SMCR: Specified Maximum Continuous Rating is the maximum output, including sea and engine margin, at which a ship's engine can be continuously operated. Ships usually run at outputs lower than the MCR, called the "economical rating."
20. SFC: Specific fuel consumption expressed as grams of fuel per kilowatt hour.
21. Type Ships. Canadian Arctic class ships designated based on their ice strengthening. See Transport Canada Publication TP 12259E (23) for details.
22. TEU: Twenty-foot equivalent Unit. A standard twenty foot container.
23. Victualing: The cost of feeding the ship's crew. Often the rate is $5/day/person.
24. VSLAM: A general purpose simulation language. Trademark of Symix systems
25. WMO ice EGG: WMO stands for the "World meteorological organisation." Ice conditions are depicted in ice charts issued by WMO using an oval shaped code, called the ice EGG. Refer to Appendix 1 for better understanding of an ice EGG.

1 Introduction

1.1 Background

The general press has reported that global warming and the resultant thawing of Arctic ice will open the fabled Northwest Passage (the sea route across the Canadian Arctic archipelago). This may result in new opportunities for the Mercantile Marine industry. It is speculated that by 2080, the Arctic Ocean will have year-round open seas. Optimists predict viable extended navigation seasons as early as 2010. The Russian Northeast passage, or the Northern sea route through Siberian marginal seas, is likely to open up much earlier due to its location at lower latitudes. This route has been studied extensively by the Russian initiative INSROP (International North Sea Route Project), and Russia has ambitious plans to commercialise it. In contrast, the Canadian route has not been well studied in terms of its potential for commercial shipping. The target markets for both routes are different. The Russian route is meant to cater to the West Europe - Japan trade and to serve as an alternative to the Suez Canal. The Canadian route, on the other hand, will be useful for trade between North America's east coast and the Far East. It is estimated that using the Canadian route will result in a saving of 4000 NM and avoidance of the bottlenecks of the Panama Canal and the Magellan Straits. In addition to providing a shorter sea route, the opening up of Canadian Arctic sea lanes will trigger development of the remote Canadian North and provide a geopolitical leverage for asserting Canada's sovereignty over the waters of the Arctic archipelago.

Technologically, ships with year-round ice-management capabilities are feasible (15); however, the commercialisation of the Arctic passage is still far from being a reality. Any pre-venture analysis of cargo-ship operations in the Arctic during the next 50 years has to factor in ice conditions. Ice is the foremost environmental factor influencing transit through Arctic waters. Even for ships with ice-management capabilities ice can result in damage to hull and propellers as well as in reduced speed. The former influences the insurance premiums and the later influences the freight rate. Accurate and realistic estimation of speed reduction and transit time is required to quantify the risk and to perform an investment analysis. A similar report on the Russian Arctic by CRREL (16) found that transit speeds were competitive during the summer months of July-October, but were not viable economically during winter.

This study aims to explore the economic viability of the year-round operation of ice-breaking cargo ships through the North West Passage, by estimating the transit times by using a simulation experiment. Based on its output, the study will compare the economic performance of the proposed Arctic transport system with that of the existing route through the Panama Canal.

1.2 Methodology

An overview of the method used is summarised below.

- Investigate the various routes through the Canadian Arctic archipelago and identify the navigational hazards along these routes. Choose the best options.
- Along the chosen routes, collect historic data for the ice regimes from Canadian regional ice charts for the five year-period 1999-2003. An "ice regime" is made up of the predominant ice types present in a geographical area at a given time. An ice type is defined by its thickness, age, concentration, and floe size. These properties are the main influence on navigational performance in ice-infested waters.
- Digitize the collected ice-regime data.
- Based on the Canadian AIRSS (Arctic Ice Regime Shipping System) algorithm (23), calculate the ice numerals for all ice-class ships. An ice numeral indicates the degree of operational difficulty posed by a particular class of ship in a particular ice regime.
- Develop a stochastic model for the ice numerals for a particular class of ship by finding the best fit probability distribution function (PDF) for a sample of ice numerals. Curve-fitting software best fit (30) was used for this purpose.
- Correlate ship's speeds and ice numerals.
- Calculate distance for each leg of the voyage by using CHS Arctic charts (1) and NOAA distance tables (19).
- Develop a simulation model by using VSLAM (32) and simulate transit of any selected ice-class ship. Calculate the transit time through a certain leg at a given

time of the year by using the distance of the leg and the stochastically assigned speed. From the model, derive the statistics for the transit time and round trips per year. Similarly, also work out the transit time and round trips per year for the Panama Canal option.

- The round trips per year represent the cargo-carrying capacity. Use them to calculate the RFR (required freight rates). Simulate this calculation by using @ risk (31) excel-addin with the stochastic inputs of the costs and round trips per year.
- Compare the options by using the RFR as an economic measure of merit. Also evaluate the sensitivities of the RFR to the various cost components.

The problem can be clearly divided into two stages: the modeling and simulation of the ships' transit and the modeling and simulation of economic performance. Section 2 of this report deals with the former, and Section 3 with the latter.

2 Simulation of Ship's Transit through Canadian Arctic

2.1 Overview of Transit Simulation

For comparing transport systems, the most common measure of merit used is the Required Freight Rate (RFR) (26, 29). To calculate the RFR, the annual cargo-carrying capacity of a potential route is required. This capacity depends on the round trips per year or the transit time and the ship's tonnage. The former is uncertain, and the latter is kept the same for the competing systems. To mitigate the uncertainty in transit time, a simulation experiment was carried out, and statistics for "round trips per year" collected. A simulation experiment involves three sequential activities or phases: input modeling, system modeling and output analysis.

Input modeling involves the following activities:

- Defining the performance measures and input parameters
- Analysing the physical system
- Defining data source and range
- Defining the relationship between the data and the input parameter; determining the correlation between the ship's speed and ice conditions
- Developing the modeling framework
- Collecting the historical data
- Digitising the data
- Curve fitting

All the above activities were undertaken in the sequence mentioned above. Input modeling is discussed in Section 2.2.

System modeling involves the following activities:

- Defining the various options to be investigated
- Defining the relationships between the various process and input variables
- Laying out the premodeling assumptions to make the model manageable
- Creating a computer or mathematical model to represent the real-world dynamics
- Running, debugging, and then validating the model
- Running the simulation experiment and changing scenarios: various scenarios were simulated by changing the design speed (from 11 knots to 20 knots) and voyage distance/terminal ports (From St. John's/Canada to New York)

The system modeling is dealt with in Section 2.3. The final phase of a simulation study is output analysis, which involves the analysis of the results and either suggesting system improvements or using the results for further studies. The statistical data collected from the study were used as input for the simulation of economic performance. This is dealt with in Section 2.4.

2.2 Input Modeling

A simulation experiment is a very powerful tool for comparing alternatives and quantifying uncertainties without undertaking a real experiment. The potential of a simulation experiment for analysing a real-world situation depends largely on the quality of the input data. Uncertainties in the input data can be represented subjectively (or epistemically) and stochastically (or aleatorily). Stochastic representation involves the collection of data either from historic sources or experimental results. Every simulation starts with a model that includes variables whose values can vary randomly and, therefore, whose values are unknown and must be sampled from an appropriate population (22). Leemis (11) and Nelson et al. (14) have emphasised the importance of random sampling from a correct distribution as the most essential ingredient of a successful simulation experiment. Hence, the aim of input modeling was to determine the correct distribution.

2.2.1 Defining performance measure and input parameters

The selection of the appropriate performance measures (the output of the simulation experiment) and the input parameters influencing the performance measure is the first step of a simulation experiment. "Round trips per year" was defined as the performance measure. The ship's speed and distance were defined as the input parameters. The distances were measured by using nautical charts (1) and distance tables (19). Distance was assumed to be deterministic and variations insignificant. Speed was modelled as stochastic and, hence, the physical system behind this parameter was studied in detail. "Round trips per year" was chosen as the performance measure for the following reasons:

- It is the main input for calculating the RFR, which was chosen as the final comparative measure of merit.
- The main differentiating factors between the competing routes, identified as the reduced distance through the Arctic, the ice conditions in the Arctic and the waiting/ transit time of the Panama Canal can all be factored into " Round trips per year."

The next step was to define the input parameters on which the performance measure depends. Round trips per year depends on a host of factors like distance, ship's speed, weather enroute, ocean currents, canal transit time, and port turn-around time. For this study, the system delays like port turn-around time were considered common to both the alternatives and, hence, were not studied in detail. However, ship's speed and distance were considered the predominant input variable likely to influence the performance measure. Ship's speed, in turn, depends on a host of factors including ocean currents, hull condition, navigational constraints, under-keel clearance, and load factor. Again, the study was narrowed down to Arctic weather, which was considered to have the most predominant influence on the ship's speed and also to be the most uncertain variable and, hence, was analysed in detail. The aim of the analysis was to identify environmental factors in the Arctic likely to have a statistically significant influence on the ship's speed. This analysis is provided in the next section.

2.2.2 Analysis of the physical system

A brief analysis of the factors affecting navigation in Arctic seas was carried out. It was found that the properties of sea ice, namely, thickness, age, and concentration, by far remain the most influential variables affecting a vessel's performance in Arctic seas. Mulherin et al. (16) classified the environmental factors that can impede commercial navigation in ice as meteorological, oceanographic, and ice-related.

2.2.2.1 Meteorological variables

These variables are the wind, superstructure icing, and visibility. Of these superstructure icing requires special mention, in the context of the polar seas. The Canadian Coast Guard publication *Ice navigation in Canadian waters* (5) identifies this variable as one of the major perils of sailing in higher latitudes. An ambient temperature of -2.2 deg c, sea temperatures below 6 deg c, and a wind speed of 17 Knots can result in superstructure icing from freezing spray, and the vessel can lose stability. However, smaller vessels are most at risk. Superstructure icing is most likely to happen in late fall or early winter and is least likely after ice cover forms. Moreover, once a vessel is in ice the chance of icing is minimal. The next major variable is visibility. Sea fog is the major cause of reduced visibility at sea and is common in many parts of the world, as in the Arctic. However, the reduction in visibility due to blowing snow, otherwise called a "blizzard," distinguishes the Arctic region. The last major meteorological variable is wind. Wind in the Arctic results from what are called the "polar lows," which are difficult to predict. Their main feature is their rapid development. They can form in as few as 12 hours and seldom last more than a day.

The meteorological variables mentioned above were not considered for the following reasons:

- Superstructure icing is not very significant for a large vessel of the size planned for the study and the literature survey did not indicate any incidents involving large vessels.
- Blizzards due to blowing snow may hinder navigation; however, with less traffic, sophisticated navigational radars, and satellite-based ice information being available, blizzards can be considered as just another common peril of sea.
- The literature surveyed did not include polar lows as a major navigational hazard
- All the factors mentioned above are highly unpredictable and require extensive study in order to include them in a stochastic model. As well, these factors were assumed to have no statistically significant influence on a ship's speed. Hence, a detailed analysis was omitted.

Oceanographic variables are discussed next.

2.2.2.2 Oceanographic variables

These variables are the waves and current. The major flow systems in the Canadian Arctic are the Beaufort gyre and the Trans polar drift. The currents caused by these are moderate and in the order of 1-2 knots. Baffin Bay has a different ocean circulation system. The counter-clockwise flow carries warm water northward along the west coast of Greenland and across the Baffin Bay at the north. This circulation results in a favourable ice condition along its path and was traditionally used by ancient explorers and whaling ships. Hence, this route hugging the Greenland coast was chosen for the model. Except for this route selection, oceanographic variables were largely ignored and assumed to be statistically insignificant. Arctic sailing conditions are no more severe than those in other oceans except for the ice conditions, which are considered next.

2.2.2.3 Ice conditions

Ice conditions are defined by the ice type, concentration, floe size, and pressure of the ice field. The presence of ice is the hallmark of polar seas and by far remains the most important environmental variable affecting navigation in otherwise relatively moderate waters. Hence, its properties were studied in detail. Mulherin et al. (16) carried out a sensitivity analysis of all the possible environmental variables relating to the transit speed in the Arctic and concluded that the ice condition was the most influential parameter. The ice condition was responsible for about 2/3 of a vessel's speed. The most important properties of ice in relation to navigation are the age, thickness, concentration, floe size, and pressure. The age of ice determines its salinity. The older the ice, the lesser the salinity and greater the breaking strength. Unlike shore ice or glacial ice, sea ice is formed by the freezing of brine. Brine crystals embedded in the lattices of ice crystals drastically reduce the brittle strength of ice. The salinity of ice is directly proportional to its rate of formation and its age. Brine drains down from the ice after its formation. This drainage is aided by the flushing of the brine by melt water during the subsequent summer. As a result, old ice, or ice which has withstood one summer melt, poses bigger hazards for shipping and requires more breaking energy. The same applies to shore and glacial ice, which is formed from freshwater. Shore ice is intermingled with sea ice in the form of bergy bits, growler and icebergs, which can cause impact damage to ships. To minimise impact damage, the presence of old ice in an area calls for cautionary reduction in speed. A higher concentration of old ice also requires ramming to achieve progress, and ramming in turn, will result in reduction of speed.

The next important factor is the thickness of the ice. The greater the thickness, the more energy is required to break it. Thicker and older ice presents the toughest conditions for navigation.

Another factor which defines an ice regime is the floe size, which affects routing decisions and decisions about whether to break through or circumnavigate a floe. In interviews reported in *Proposed Ice Regimes for Arctic Ship Navigation* (10) many ship's Masters stated that even in good visibility exceeding six miles, the edges of floes larger than two miles cannot be seen. Hence, smaller floe size is likely to result in better piloting judgements. Floe size is most important in higher concentrations of ice where there is less chance of routing (10).

Another important property of an ice field is its internal pressure. Pressure and ridging are caused by external conditions. Unlike the properties of the ice itself, pressure can change rapidly. Pressure inside an ice field is caused either by wind forcing the ice against a landmass or constrained expansion during formation (5, 16). Next to impact with glacial ice, encounters with ice pressures are the most hazardous for ships. Pressures can magnify the impeding effect of any high ice concentration (10). No method exists for measuring pressure directly through satellite imagery or observation, so mariners often experience pressure unexpectedly.

Based on the study of the physical system, the ice condition was assumed to be the main variable which can influence speed while sailing in the Arctic. Hence, an input model based on the variability of ice had to be built. The following methods were available for building such a model:

- By using the historical data for ice conditions.
- By conducting designed experiments including actual transits or data for actual transits.
- By correlating backwards to the parameters affecting ice formation, such as summer temperature normals, ocean circulation patterns, precipitation patterns, and snow cover.

Going backward would take the problem to the realm of meteorological science and would involve complex mathematical modeling. Data pertaining to year-round transit by Canadian Arctic Class (CAC) ships are scanty or not available. Hence, the only option left was to develop a model based on the historical ice data. Building a model from historical data requires definition of the data's source and boundaries. For this purpose, the temporal and spatial variations of the ice conditions were studied.

2.2.3 Defining data source and range

With ice as the potential navigational impediment, various routes available through the Arctic archipelago were studied, and two potential routes were selected for further analysis thus, defining the data's spatial range. The time span for the historical data was chosen by analysing the long-term variations of the ice conditions. Historical information on the ice conditions in the Canadian Arctic is available in the Ice Charts Archive of Environment Canada (8, 34). The method of data presentation in the ice charts is described below.

2.2.3.1 Data source

Ice conditions are depicted in ice charts issued on a regional (weekly) and local (daily) basis. Ice charts define an ice type using its age, thickness, and floe size. A given geographical area may have different ice types. The concentration or extent of each ice type in a given area determines the ease of navigation. The Canadian Arctic Ice Regime Shipping System Standards (AIRSS) (23) defines an ice regime as a "Geographically continuous area having a relatively consistent distribution of any mix of ice types including open waters during a particular time." An ice chart shows all the ice regimes present in a region like the western arctic for example, on a particular date. However, the ice pressure and ridges in an ice field are not represented the ice charts. Each ice regime is pictorially represented by an oval-shaped WMO ice EGG code. The ice EGG code describes the following properties:

- Stages of development or age and thickness represented by a number called the "ice type."
- Total Concentration. Concentration is expressed as a fraction of the ice in water and is reported in tenths.

- Partial Concentration of a particular ice type. The thickest, the second thickest, and the third thickest are reported in tenths.
- The form or floe size of each ice type.

The procedure for reading an ice EGG, the ice type nomenclature, and a sample ice chart are explained in Appendix 1.

Ice regimes are transient, and their temporal as well as spatial variability has to be incorporated into a model. A brief analysis of the temporal variation of the ice condition was carried out.

2.2.3.2 Selection of temporal range of data

Polyako et al. (21) studied the temporal variation of the ice regime and found that changes in ice conditions are episodic events rather than long-term shifts. Their studies of the Russian ice observations in the Siberian coastal seas indicated that long-term shifts are small and statistically insignificant. The variability of the Arctic ice is dominated by multi-decadal low-frequency oscillations (LFO) and decadal variations, which are characterised by geographical differences; for example, decadal variations are more pronounced in the Chuchki Sea than multi-decadal LFO variations are in the Kara Sea. Polyako et al. (21) found that sea's ice cover lost at one place is gained elsewhere and maintains a balance over the whole ocean. Holloway and Sou (7) referred to reports in the popular press and scientific literature linking Arctic ice-thinning to global warming as nothing but the outcome of the selective interpretation of data. The reported rapid loss of Arctic ice cover is based on submarine sonar data from mid-1960 to 1990. Holloway and Sou (7) attributed these report to under-sampling both spatially and temporally. A dominant cause of variability was the wind-induced movement of ice from the central

Arctic to the Canadian sector. None of the submarine tracks were through the archipelago or the Beaufort Sea. Holloway and Sou (7) further argued that a half-century time series revealed no significant loss of ice volume. An increase in ice volume occurred until the mid-60's, followed by a period of decadal variation with no significant trend until the mid-1980 and then abrupt loss. Koberelle et al. (9) supported this view. The large decadal and multi-decadal trends tend to mask long- term trends. The failure and success of the early Arctic expeditions can be attributed to the large multi-decal variation in Arctic ice conditions. Parry succeeded where Franklin failed, and the whale-hunting Thule people migrated from the Canadian shores probably because of this multi-decadal variation.

If strong multi-decadal variations of ice volume exist, a long time series analysis of ice data is required to quantify risk to shipping during an extended season.

However, due to resource constraints, this study was restricted to incorporating only decadal variations. In addition, it was also assumed that if conditions were currently favourable, the next multi-decadal high could be expected only after about 25 to 30 years, which was more than the time span envisaged for the venture. A five-year time span preceding the year 2003 was chosen as this span was likely to represent at least one decadal high and low. The decadal variation was observed to drop from a peak in 1993 to a low in 1998 and to rise again to a high in 2003. Hence, a time span of 1999 to 2003 was chosen. However, for the years analysed, all available Canadian ice data were used. The data were restricted to Canadian marginal seas along selected routes. The criteria for the spatial range selection are dealt with in the next section.

2.2.3.3 Selection of the spatial range and routes

The major routes used by Arctic supply ships as listed in the Canadian Arctic sailing directions (2, 3, and 4) were considered. These routes are marked in the chart placed in Appendix 2. The eastern entrances to all the routes lie through Lancaster Sound. Experience has shown that ice conditions make the alternative passage through Fury and Helca Straits too difficult to consider (2). From Lancaster Sound, the following passages exist.

- The first route leads from Lancaster Sound through the Prince Regent Inlet, Bellot Straits and Franklin Straits. From here this route continues through the James Ross Straits and Rae Straits, then through the Simpson Straits and the Gulf and the straits bordering the mainland coast (The Queen Maud Gulf, Dease Straits, Coronation Gulf, Dolphin and Union Straits to the Amundsen Gulf and then the coastal route west through the Beafort Sea).
- The second route leads from Lancaster Sound through the Barrow Straits and Peel Sound, south to the Franklin Straits. From there this route continues south and west through the coastal waterway mentioned above.
- The third route considered a possibility due to the favourable ice conditions reported in the year 2003 leads south from the Barrow Straits through the M'Clintock Channel or Peel Sound and the Franklin Straits to the Victoria Straits and from there continues to the Queen Maud Gulf through the western shore of King William Island.
- The forth route follows Parry Channel (It consists of the Barrow Straits, Viscount Melville Sound and the McClure Straits, the waterway south of Queen Elizabeth Island and north of Victoria island) from Lancaster Sound

westward to the entrance of the Prince of Wales Straits separating Bank Island and Victoria Island, south to the Amundsen Gulf and then west through the Beafort Sea to the Bering Straits.

- The fifth route follows the Parry Channel west from Lancaster Sound to the western entrance of the McClure straits, turns south-west along the west coast of Bank Island, crosses the Amundsen Gulf and then continues west through the Beafort Sea to the Bering Straits.

The first two routes have draught restrictions and pass through a maze of islands and shoals. These routes are the warmest, with mean temperatures during July and August between 7 and 10 deg c, with highs of 26 deg c. However, ample depths for medium-draught vessels exist along the route only as far east as Nordenskiold Islands, near the centre of the Queen Maud Gulf when approaching from the west. Further east, navigational difficulties arise in the Queen Maud Gulf as well as in the Simpson Straits leading out of it. The track through this area is tortuous and abounds in shoals (2).The third alternative is to detour through the Victoria Straits instead of the Simpson Straits. This route has deep waters and is fairly straight but is likely to have the worst ice conditions along the coastal route. Normally, one to three tenths of the old ice embedded in five to eight tenths of the first-year ice remains in the Victoria Straits and Larsen Sound during the navigation season; however, in the 2002/2003 season, all the ice had melted and the freeze-up had began later than usual. Hence, this route was considered for the study.

The last two routes are best suited for deep-draught vessels. Of these two, the fourth route through the Prince of Wales Straits is the most promising as the ice conditions in the west and north side of Bank Island make the fifth route difficult (4). The route through the Prince of Wales Straits was successfully navigated by the SS Manhattan in September 1969. However, one obstacle along this route is the north entrance of the Prince of Wales Straits and Viscount Melville Sound. This route was also investigated.

Based on the issues discussed above, the study was restricted to the following routes:

- Davis Straits-Baffin Bay-Lancaster Sound-Peel Sound-Franklin Straits-Victoria Straits-Queen Maud Gulf-Dease Straits-Coronation Gulf-Dolphin and Union Straits-Amundsen Gulf-Beafort Sea –Bering Straits, marked "1" in the accompanying chart placed in Appendix 2.
- Davis Straits-Baffin Bay-Lancaster Sound-Barrow Straits- Viscount Melville Sound-Prince of Wales Straits-Amundsen Gulf-Beafort Sea –Bering Straits, marked "2" in the accompanying chart placed in Appendix 2(41).

The routes are covered by the Canadian regional ice chart for western and eastern Arctic. The western extremity of the ice chart lies off Point Barrow. The passage from Point Barrow to the Bering Straits was assumed to have the same ice conditions as those in the Beafort Sea. New York and Yokohama were chosen as the terminal ports as this route was assumed to have unlimited cargo-generation capacity in all segments of the industry. In addition to Arctic transit, this route includes open water legs from the Bering Straits to Yokohama and from New York to the Davis Straits. Open water was assumed to be present, even though the winter ice line extends well below the Bering Straits and the Davis Straits because the ice conditions are not severe for an ice-class ship in this region. After deciding on the spatial and temporal boundaries, the next step was to develop a correlation between the primary input (ice condition) and the secondary input (ship speed).

2.2.4 Correlation between ship's speed and ice conditions

The properties of ice affecting navigation were identified as ice type (age and thickness), concentration, floe size, and pressure. To link the ice condition to the speed, the ice numerals used in the Canadian Arctic Ice Regime Shipping System (AIRSS) (23) were chosen. Canadian standards for the construction and classification of ice-strengthened vessels were assumed. A Canadian Arctic class vessel the CAC1 has the highest ice strength, followed by the CAC 2, 3 and 4. The class ships are superior to Type ships (E to A) and are meant for an ice-breaking role. The AIRSS deals with vessels of the CAC3 level and below. Higher ice-class vessels are yet to be designed (Refer Appendix 3 for further information). The ice numeral serves as a performance measure for a vessel in ice-infested waters, based on the vessel's ice strength (in terms of Canadian ice class), ice type (age and thickness), and concentration. The AIRSS ignores the effect of floe size on speed. The ice chart's data do not include the pressure or ridging. Hence, this method omits the effect of floe size and pressure on the ship's speed. Mulherin et al. (16) treated concentration and thickness as independently occurring variables and modelled them separately, thereby creating ice regimes from two separately drawn Monte Carlo samples for these parameters. However, ice numeral calculations consider ice regimes as a single variable.

The ice chart data is converted to an ice numeral (indicating a ship's ice strength) for each ice class by using an algorithm defined in the AIRSS. The algorithm employs a matrix of ice multipliers for each vessel class and ice type. The concentration of each ice type is multiplied with the multiplier, and the product for all the ice types in a regime is added to get an ice numeral unique for the vessel class and ice regime. This calculation procedure is presented in Appendix 3. The main drawbacks of using the AIRSS ice numerals to define ship's speed were identified as follows:

- The system was developed with the primary aim of ship's safety with respect to hull damage and oil spills, and no correlation with performance was incorporated into the system
- The system ignores the floe size as a property of the ice regime. This omission may not be important in terms of safety, but the floe size has a profound effect on optimum routing and hence the speeds possible through ice.
- The system accounts for ice pressure and ridging; however, this property is not reflected in the ice charts, thereby making it impossible to obtain historical data.

Mulherin et al. (16) linked ice pressure to concentration and assumed that for high pressures to develop, a 100% ice with no open water (10/10th concentration) is required. Mulherin et al. (16) based their model on this assumption. However, a 100% concentration does not necessarily imply a high pressure condition. The AIRSS (23) stipulates reducing the ice multiplier values by one if the concentration exceeds 6/10, and if 3/10th of that ice is ridged. However, because of the lack of information on ridging in the historical data, the application of this rule becomes impossible. One solution would be to assume a worst-case scenario and apply the ice pressure rule to all concentrations of 10/10.The calculation below illustrates the effect of applying this rule to an ice regime of consolidated (10/10) thick first-year ice (ice type 4.)

Without reduction for pressure:

Ice type: 4*; Concentration: 10

Corresponding ice multiplier for CAC3 Ship: **2**

Ice numeral: 2*10 = **20**

With reduction for pressure:

Ice multiplier with reduction for pressure: ***1***

Ice numeral in pressure field: ***10***

The above calculation indicates that a blanket pressure correction for all concentrations above 9/10 will result in a highly pessimistic estimate. Hence, it was decided to ignore the pressure correction all together. Mulherin et al. (17) assigned the occurrence of pressure from a Monte Carlo sample and applied speed reductions based on the prevailing concentration. This model can be embellished to establish a worse-case scenario by incorporating an equally likely probability for pressure occurring in a regime with consolidated ice, especially for Lancaster Sound and the Coastal Straits, which were identified as pressure-prone(2,3,4,5).

The other property not included in ice-numeral calculations was the floe size. Better estimates of the floe size can be obtained by using advancements in remote-sensing technology. The use of neural nets for routing decisions and smart lookouts with the help of devices like pilotless aircraft on ships are likely to make floe size a statistically insignificant variable by the time the venture develops into a commercial operation. Hence, influence of floe size was not factored into the model.

The ice type (age and thickness), its concentration, and the vessel's ice class were the only variables factored into the ice numerals calculated by using the above assumptions.

Also, the ice numeral is a measure of a ship's performance, not the actual speed, and can be used only as a scaling factor for the design speed. The estimation of actual speed from the ice numeral is dealt with in system modeling.

At any time, the ice conditions will differ greatly along the long Arctic route. Hence, it has to be divided into short segments where consistent ice conditions can be assumed, or, in other words, the spatial grid has to be defined for the model. An input and system model has to be built on this framework. The segmentation of the route and the allocation of ice regimes for each segment depending on their length and consistency are discussed in the next section.

2.2.5 Developing the modeling framework

The simulation software VSLAM (32) used for transit analysis is a network-based simulation tool which allows pictorial representation of a system. This software is ideal for modeling the flow process, where as time advances, a set of events occurs in a logical sequence. The basic framework of a VSLAM model is an entity flowing through a network consisting of nodes connected by activities. The nodes can have many features but they basically represent an event or a change of state in the system. At the nodes, decisions regarding the path to be followed by the entity or a change of the entity's attributes takes place. An event (node) occurs at a single point in time and is the end /start of an activity. Activities may provide simple connectivity or conditional branching or represent a delay between nodes. Thus, as time advances, an entity jumps from one node to the other, subject to certain decision rules, thereby simulating the dynamic behaviour of the system. This event-based approach facilitates the modeling of systems like assembly lines, queues, and traffic flows. A discrete-event approach was used in this study. In discrete-event systems, changes occur only at event times, and the system's state remains constant between events. A dynamic portrayal of the system is obtained by advancing the simulation time from one event to the next by following the network paths. The status variables are examined only at the event times. For this study, the route was divided into a number of legs ending/beginning at way points represented in the model as nodes. The distance between the way points can be viewed as the spatial grid for the model. Mulherin et al. (16) chose a spatial grid representing 8 hrs sailing by a 17 knots ship. They then modified it by 2 hrs to check the impact of suddenly changing ice conditions. However, no significant change in simulation output was noticed. Hence, in choosing way points, primary consideration was given to including areas with similar ice conditions in one leg. For example, the whole of the Amundsen Gulf experiences unique ice conditions due to the presence of the Bathurst Polynya. Hence, the Amundsen Gulf was modelled as one single leg. Then description of the different legs along the coastal route is presented in the passage plan in Appendix 4. The time (activity duration) taken to traverse the distance between the way points (nodes) was calculated from the ship's speed and the distance between the nodes. The speed depended on stochastically established ice conditions. Thus, the ship was made to sail from one node to another with a speed assigned at the start node based on an ice numeral sampled stochastically. The speed was assumed to be constant between nodes. Once the ship reached the next node, another assignment of speed was made depending on the ice condition prelevant at that time and the place where the node was located, thus simulating the spatial as well as the temporal advance of the ship. The legs, way points, distance and allocation are shown in

Appendix 5. After defining the basic framework, the next step was to collect the historical data. The procedure and assumptions made are described in the next section.

2.2.6 Collection of historic ice data

Data were collected from regional ice charts of the Canadian ice service. Regional ice charts from 01 Jan 1999 to 01 Dec 2003 for the western and eastern Arctic regions were analysed. The eastern Arctic chart covers the route from the Davis Straits to the western exit of Lancaster Sound at Resolute. The western Arctic chart covers both the southern and northern routes from Resolute in the east to Point Barrow in the west. Every year, regional charts are issued monthly from January to April and December, biweekly in May, then weekly from June to November. A spreadsheet-based model was developed for digitising and converting the ice codes to ice numerals. The ice regimes along the selected routes were identified. Their types and concentrations were input into the model. Based on this information and the ice multiplier algorithm, the model then calculated the ice numeral corresponding to each ice regime. The ice numerals calculated by the model were grouped into different legs, along the routes, in the same spreadsheet in a routing table. The model was replicated for each ice chart. A total of 310 charts were analysed, and 2366 ice regimes were digitized. The collected data were then collated into another spreadsheet on the basis of the ship's ice class, the time of the year, and the geographical region. The procedures followed for the digitization of the ice codes are described in the next section.

2.2.7 Digitization of historic ice data

The method followed and assumptions used for digitising an ice chart are described below:

- A rough course was traced on the chart, and all the ice regimes encountered were marked.
- If a very tough regime surrounded by easier regimes was encountered, the easiest path likely to be followed by the ship was chosen, and the regimes encountered were marked. However, if a tough regime partially blocked a path, then it was marked.
- Each leg was allotted a fixed number of ice regimes based on the length of the leg. For example, two regimes were allotted for the Amundsen Gulf.
- If more than the allotted number of regimes were encountered, all regimes were marked.
- If a lesser number of regimes were encountered, the allotted quota was filled proportionally by the regime present.
- If more regimes than the quota were present, all were marked, even if some of the regimes occurred only in a small area. In this case, to avoid unequal representation of the prominent regimes, the quota was exceeded. Thus, despite the subjectivity, all regimes received proportional representation along the route.
- The type and concentration of all the marked regimes in a chart were entered into a spreadsheet, model which calculated the ice numeral for all Type ships and CAC4/3 ships, from the AIRSS ice multiplier algorithm incorporated into the spreadsheet.

- In the case of an ice type (9.) occurring outside an ice EGG, a partial concentration of 1 was allotted to the multiplier for (9.), to account for the precautionary reduction in speed because of the presence of second-year ice in the area.

In the same spreadsheet, the regimes were entered into a routing table in the same order as they occurred along the route. The ice numerals already calculated were copied into the routing table by using the Excel lookup function. A sample ice chart and its corresponding spreadsheet model are presented in Appendix 6. After preliminary analysis, it was concluded that the northern route through Viscount Melville Sound was not navigable for most of the year. Hence, it was decided to limit the study to the coastal route. The draught restriction in the route was assumed to be 12 meters. The data collected were again filtered for the CAC3 and CAC4 Class of ships and grouped based on the time of the year and the legs. The spreadsheets for the CAC3 ship are presented in Appendix 7. From the data so tabulated, it was evident that year-round navigation was not viable for a CAC 4 ship due to the occurrence of ice numerals of less than -5, which indicates very severe ice conditions and the likelihood of the ship getting beset. Hence, it was decided to narrow down the scope of the study to the sturdier CAC3 ship alone. The next task was to construct appropriate probability distributions for the ice numerals calculated for the selected class of ship and route. The procedure followed is discussed below.

2.2.8 Curve fitting and transfer of input model to the system model

Defining probability distributions for sample data will help the simulation software to randomly sample from the distribution, giving a real-time representation of the system. A student version of the curve-fitting software BESTFIT (30) was employed for constructing probability distribution functions (PDFs). The PDFs constructed from the historical data (the ice numerals for CAC3 ships) are presented in Appendix 8. The current version of BESTFIT comes as EXCEL-Add in. This feature facilitated the selection of the required sample from Appendix 7, which is an EXCEL worksheet. The procedure involved selecting the ice numerals for a specific week and leg and fitting a distribution for this selection. The output window of BESTFIT lists the fitted distributions, their ranking according to various goodness of fit tests, the Probability – Probability (P-P) plots, Quantile – Quantile (Q-Q) Plots, graphical comparison with the histogram for the data superimposed on the distribution curve, and comparison statistics for the distributions. The best distribution was selected by considering all these factors. The decision rules followed for selecting the best distribution are given below.

- Even though BESTFIT allows for the fitting of 28 distributions, all of them could not used due to the limitations of VSLAM. The distributions permitted in VSLAM and their parameters are shown in Table 1. From the ranking given in the fit results, the top-ranked distribution available in VSLAM was selected. Most of the fit results were from the list in Table 1 and were acceptable in VSLAM.

Table 1: Distributions available in VSLAM adapted from (28).

Distribution	**Factor 1**	**Factor 2**	**Factor 3**
Beta	Theta	Phi	
Erlang	XK		
Exponential	Mean		
Gamma	Beta	Alpha	
Poisson	Mean		
Log Normal	Mean	Standard Deviation	
Normal	Mean	Standard Deviation	
Triangular	Low Value	Mode	High Value
Uniform	Low Value	High Value	
Weibul	Alpha	Beta	

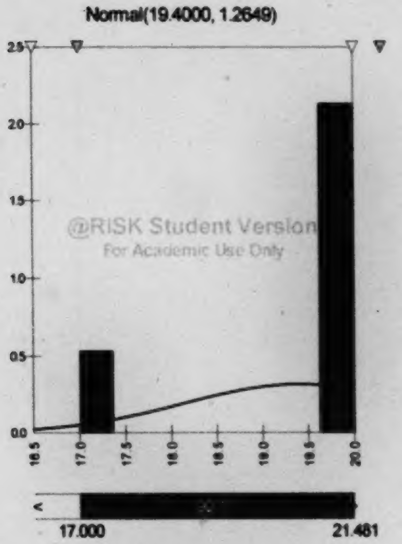
- BESTFIT allows for the fitting of continuous as well as discrete data. The fitted data (ice numerals) were integers, and a discrete distribution would have described them better. However, if the discrete option is chosen, the fits will be limited to Poisson and Uniform distributions. Despite being a discrete variable, the ice numeral can be assumed to indicate a ship's performance on a continuous scale. The discreteness of the ice numeral results from the ice EGG data and ice multipliers being integers. The ship's speed, which is correlated to the ice numerals, is a continuous variable. The relationship between these two can be derived from a linear regression equation based on the sailing data for at least low- speed ships. (Refer to system modeling, Section 2.3). Hence, a continuous scale was chosen for the ice numerals.
- The fit results were ranked by using the Chi-Square, Anderson-Darling (A-D), and Kolmogorov-Smirinov (K-S) fit Statistics. Each method has certain drawbacks. The Chi-Square method is characterised by the arbitrariness in the number and location of bins, resulting in different results for the same sample.

The K-S method does not detect tail discrepancies and focuses on the central portion of the curve. The A-D method focuses on the tail portion of the distribution (20, 30, and 32). Hence, the distribution with the top ranking in all three fit tests was selected. If no distribution satisfied this criterion, then the one with the top ranking in two tests was selected. If no distribution had a top ranking in two tests, then the decision was based on graphical comparisons.

- BESTFIT allows for graphical comparison by superimposing the fitted distributions on the sample's histogram. In addition allowing for visual judgement, the graphs also feature sliding lines which can be dragged to select a range for the data, and the percentile for the range can be read. This feature helps in comparing two distributions by evaluating the percentile values for a selected range, thus reducing the subjectivity in visual selection. In certain case, a selection was made by visual comparisons even if the fit test ranking was low. One such example involved a sample consisting of two values, 17 and 20. Even though normal distribution was ranked top by the A-D and K-S method, a visual inspection showed that only 92% of the sampled values were likely to fall in between 17 and 20, so a Beta general with the lowest ranking in all the three fitness test was selected as 100% of the values fell in the range 17 – 20 (See Fig 1&2). Also, the middle portion between 17.5 and 19.5 for which the sample had no values was more suitable for the Beta general as only 15.3% of the values were likely to fall in this range as against 48.1% for a normal distribution (See Fig.3 & 4).

Table 2: An Ice Numerals Sample (Amundsen Gulf - 03 rd week of Oct; CAC 3 Ship)

20	20
20	20
20	20
17	17
20	20



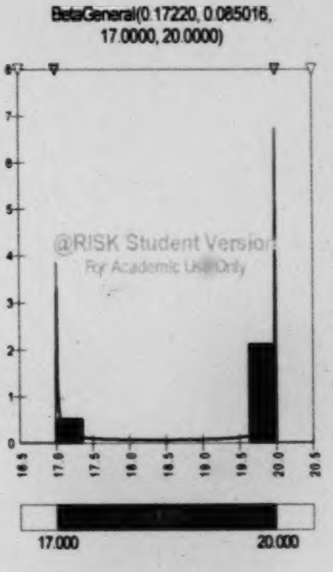
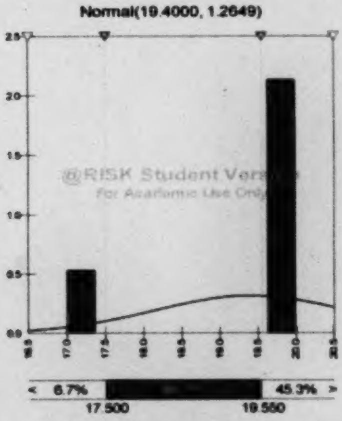


Fig 1: Normal distribution range 17 -20 Fig 2: Beta distributions range 17 – 20



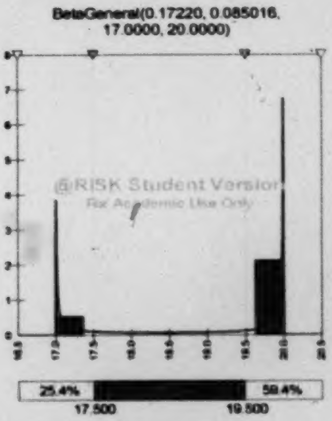
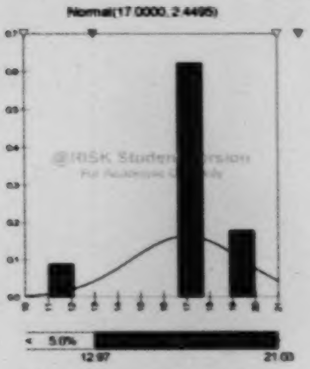


Fig 3: Normal distribution range 17.5 -19.5 Fig 4: Beta distributions range 17.5 -19.5

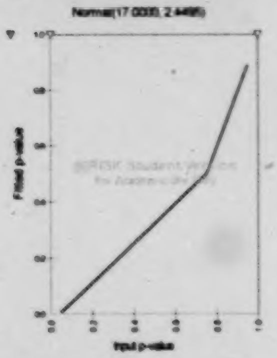
- If a visual test could not determine the selection, then the statistics (mean, mode, variance Kurtosis and skewness) of the fitted distributions were compared to arrive at a decision.
- Finally, the P-P and Q-Q plots were examined to arrive at a decision. An example of a decision made by using the linearity of the Q-Q plot as a criterion is given in Fig. 5, 6 and 7. The Beta general was ranked first by K-S and Chi-sq Statistics; however, Normal distribution was selected even though it was ranked top by only A-D Statistics. The data pertaining to this example are given in Table 3.

Table 3: Ice numeral sample (Amundsen Gulf – 01st week of April; CAC 3 Ship)



17	17
20	20
11	17
17	17
17	17

Fig 5: Normal distribution



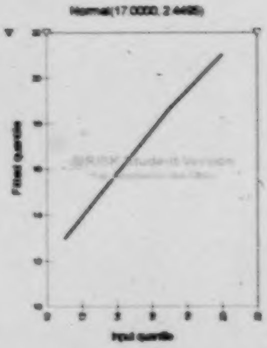
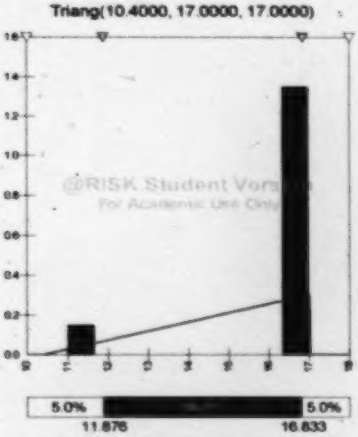


Fig 6: P-P Graph

Fig 7: Q-Q Graphs

- Even if the fit statistics were in agreement, Beta general was used if the sample had only two values. This kind of sample with ice numerals of 17 and 20 was encountered many times. The sample was the result of a correction applied to an open-water regime, whenever Bergy bits were present. This correction was meant to account for the precautionary reduction in speed while sailing in Bergy water.
- In case of a highly skewed sample, Beta general or Triangular distribution was preferred over the recommendation of the fit statistics. Figure 8 shows a Peel Sound regime, where triangular distribution was chosen due to the skewness of the sample.

Fig 8 & Table 4: Peel Sound ice numerals and distribution - 01 June



17	17	17	17
17	17	17	17
17	17	17	17
11	11	17	17
17	17	17	17

- For a CAC3 ship the ice numerals range from 20 to (-) 10, representing open water and consolidated multi-year ice, respectively. However, the range of the fitted distribution was not restricted to these limits, as doing so would have resulted in fewer choices of distributions. An ice numeral greater than 20 and less than -10 does not make any sense as far the physical system is concerned; however, the number of samples in the extreme tail region was assumed to minuscule and was not likely influence the results. To account for a few ice numerals outside the chosen range, provision was made in the system model to route them out of the network and to keep a count of such occurrences.

- Poor fitting was observed in most cases. Hence, emphasis was on visual selection rather than on relying on fit tests. As a rule of thumb for visual fits, the middle portion of a distribution was assumed to represent the performance expectation, and the tail the risk expectation. Hence, the emphasis was on the conformity of the sample to the middle portion of the distribution curve, rather than to the tails, because the primary objective of the study was to develop a performance measure rather than a worst-case scenario.
- The Beta general output of BESTFIT is in the form of shape and form factors (Theta and Phi) and the minimum and maximum values which define the range. The input to VSLAM are the arguments (Theta and Phi), and VSLAM returns a value in the range 0-1. To convert this into a sample from the finite range, the following equation was used (28):

$$\text{BETAT} = \text{BETA}(\text{Theta}, \text{Phi}) * (\text{Bmax} - \text{Bmin}) + \text{Bmin}.$$

After defining the probability distributions, the next task was to assign VSLAM global variables to the distributions so that they could be input into the VSLAM network. A total of 144 distributions were fitted to the whole data. The sample identities (the names of the leg, week, and month), the fitted distribution, and the global variables assigned are presented in Appendix 8. The next activity, system modeling, is described in the following section.

2.3 System modeling

The basic concept of the VSLAM model for the transit system was defined in Section 2.2.5. Before proceeding to a discussion of the network building, it is worthwhile to consider the various pre-modeling assumptions and to define the scenarios and the relationships among process parameters. The scenarios or system alternatives planned for investigation are discussed in the next section.

2.3.1 Defining the scenarios to be investigated

One pre-modeling task is to define the alternatives to be investigated. The shipping industry is dominated by three major market segments: liner (container) shipping, bulk solids (bulk carriers), and bulk liquids (oil, chemical, and gas tankers). Each segment is characterised by different type of ships with different specifications. Hence, a decision on the market segments to be investigated had to be made prior to modeling. The tanker option was not considered due to stringent construction standards (23) and the uncertainty associated with oil spills. The latter would result in high uncertainty in insurance premium estimates. Hence, the focus was restricted to bulk carriers and container ships. The bulk carrier segment is characterised by cheap and slow-speed ships with design speeds ranging from 8 to 13 knots and built to bare specifications. The container market is characterised by high-speed ships with improved reliability. As the study aimed to compare the Panama Canal route with the Arctic route, a Panamax-size ship was chosen to maximise the benefits of economy of scale. (The Panamax size ship has the maximum dimensions permitted for a Panama Canal transit). The typical dimensions of a Panamax bulk carrier adapted from (29) are given in Table 5 below. The typical characteristics of a Panamax-type container vessel are given in table 6 below (29).

Table 5: Dimensions Panamax Bulk carrier

Length(Meters)	220
Draught (Meters)	11.7
Beam(Meters)	32
Dwt(Metric tons)	60000
Speed(Knots)	11

Table 6: Dimensions Panamax container

Length(Meters)	281
Draught(Meters)	12
Beam(Meters)	32
Capacity	3000 TEU
Speed(Knots)	22

At this stage, the only parameter of interest was the design speed. The next scenario to be defined was the terminal ports. The Pacific port was chosen as Yokohama in all cases, and the North Atlantic ports of St. John's and New York were considered as competing alternatives. New York was chosen because of its unlimited cargo generating potential. St. John's was chosen as it is a major way point for traffic originating from/through the St Lawrence Seaway and the Great Lakes. The distances were worked out from the Canadian Arctic charts (1), the Arctic sailing directions (2, 3, and 4) and the distance table (19). The distance saved in both the cases is shown in Table 7 below. The various way points used for this calculation are presented in Appendix 4.

Table 7: Distances between terminal ports

Origin	Destination	Distance Through Arctic	Distance Through Panama	Distance Saved
Yokohama	New York	8109 NM	9778 NM	1669 NM
Yokohama	St John's	7016 NM	10504 NM	3488 NM

Hence, it was decided to model these four combinations: the terminal ports of New York and St. John's in combination with a slow-speed 11 knots and a high speed 20 knots vessel. After deciding on the alternatives, the next step was to define the relationships among the process variables.

2.3.2 Defining the relationships among the process variables

The two relationships to be incorporated into the transit model were: the one between the ice numeral and the speed, and the one between the speed and the transit time for a leg. The transit time was obtained by simply dividing the distance of the leg by the assigned speed. The speed assignment corresponding to a sampled value of ice numeral; however, required further investigation. The relationship between the ice numerals and safe speeds was investigated by numerous field validation studies of AIRSS conducted by the Canadian coast guard. A summary of these studies is available in the report titled "Safe speed in ice (14)." The report and all the validations studies agree on the significant positive correlation between the ice numerals and a ship's speeds. For all ice numerals below 15, ice is the predominant factor influencing speed, and in this range, the ice numerals are best predictors of the speed. For ice numerals above 15, ice conditions become secondary, and other factors take precedence (14). However, all the studies were for slow-speed Type ships (Type B, D, and E Vessels).

One study (14) analysed 362 transits by Type ships, and a regression curve was fitted to the data. The curve was defined by the following equation:

$$y = 0.0022x^3 - 0.0397x^2 + 0.2834x + 3.5729.$$

The curve represents a maximum speed of 11 knots at ice numeral 20.Hence, this curve is ideal to represent an 11 knot ship, and for this reason, 11 knots was selected as the design speed for the bulk-carrier (slow-speed) option. The report (14) also provides a regression curve for unsafe speed. This curve was based on the recorded average speed leading up to ice damage. The unsafe speed curve is represented by the equation given below:

$Y= 0.0001*x^3-0.0072*x^2+0.2616*x+7.5938$.

The safe speed curve for a CAC3 ship is likely to be steeper than that of a Type ship. However, no transit data exist for a CAC3 ship. Hence, the safe speed for CAC3 ship was assumed to follow a linear relationship and to lie in between these unsafe and safe speeds. Figure 9 shows all the three relationships. Both the safe-speed and the linear relationship options were chosen for the slow- speed model. No validation study exists for high speed-ships. Hence, it was decided to adopt a linear relationship with an intercept of 6 knots and a speed of 20 knots, corresponding to the ice numerals of 0 and 20, respectively. This relationship can be expressed by the equation $y = 0.7*x + 6$. A curve representing this relationship is shown in Fig. 10. This curve was assumed to lie between the unsafe and safe curve of a 20 knot Type ship and, hence to be ideal to represent a 20 knot CAC3 ship.

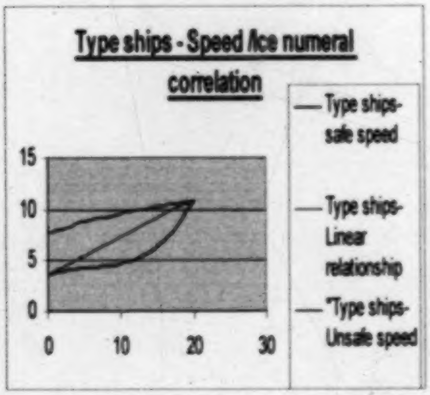


Fig 9: 11 knots ship

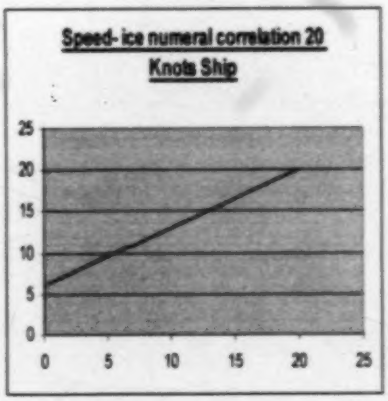


Fig 10: 20 knots ship

Relationship between speed & ice numeral

After defining the scenarios and the process relationships, the simplifying assumptions were identified.

2.3.3 Pre-modeling assumptions

Simplifying assumptions are necessary to make a model manageable. Most of the assumptions were covered in the discussions of the input modeling. The ones left out are highlighted here.

- The condition during one leg is independent of its preceding or following state, so that means an open-water condition may be followed immediately by a state of consolidated multi-year ice. However, this phenomenon will not affect the system's overall performance as the results of the experiment are obtained as a statistical value.
- No negative ice numeral value was used for speed calculation. If a negative ice numeral less than 0 and greater than or equal to -5 occurred, the service of an escort ice breaker was used. If ice numeral values below -5 occurred, the vessel was assumed to be beset.
- Beset vessels were kept beset for 168 hrs, or one week, and then sent back to the start of the leg. A count of such occurrences was taken.
- The availability of ice breakers was assumed to be instantaneous and at all locations.
- When an ice breaker was used, the speed was assigned as 5 knots, and the leg completed at this speed.

- The legs were assumed to be direction-independent, so that a transit from the Labrador Sea to New York was the same as that from New York to the Labrador Sea.
- The average deployment of a polar ship was assumed to 350 days per year, with 15 days for dry docking, amounting to 50 weeks or 8400 hrs of earning days. Earning days were considered to be on hire days, which include sailing as well as port stays for cargo work.
- No ballast (empty) passage was considered and 100% cargo availability was assumed, both ways.
- The average deployment of a bluewater ship was assumed to be 360 days, with 5 days for dry docking. The dry dock period for polar ships was assumed to be more to account for the additional time spent for repairing ice damage.
- The port-stay time is a highly unpredictable factor and hence was assumed to be uniformly distributed in a likely range.
- The speed in open water was assumed to be triangularly distributed with the design speed (the continuously rated speed) as the maximum and mode value, and the minimum value being 15 % less than that of the continuous speed. This assumption was made to account for the reduction due to the vagaries of the sea. A Triangular distribution is most appropriate when knowledge of a system's behaviour is limited, whereas the data range is known.

After considering the simplifying assumptions, alternatives, and process relationships, the actual network was modeled. The VSLAM network is described in the next section.

2.3.4 Creating a computer model: Network modeling

The approach was to create a simple version of the network first and then to embellish it to represent the complete system. The steps involved in the model building are described below. A VSLAM network basically consists of a network, an entity traversing the network, and the resources used by this entity to complete its activities. The ship was modeled as an entity. The ice breaker and a best condition were modeled as a resource so that the utilisation statistics could be collected.

- The first version was modeled to represent one single transit from Yokohama to New York. All decision rules and input assignments were incorporated into this version. The performance measures used were "time in system" and "average speed." The simulation was run for 300 runs. The main purpose of this step was to verify the model. The AWESIM interactive window for VSLAM allows interactive execution so that each step of the run can be visualised, and the real-time changes of the system's variables can be viewed. This step is very valuable for debugging programming errors. An interactive execution of this version was carried out.
- The model was then embellished by changing the sailing dates from Yokohama starting every month, and statistics on" average speed" and "time in system" were collected.
- The next step was to embellish the model for round trips. The start was kept on the first of January at Yokohama, and the vessel was made to transit eastward and then westward, continuing until 31 Dec, and the "round trips per year" were calculated. The other performance measures were time in Ice, time in open water,

port stay, canal-water time, repair days and total distance. These were calculated to work out the cost elements for the economic model.

- The Panama Canal transit was then modeled and the "round trips per year" for that option calculated.

The final network for the Arctic and the Panama versions is described in the next section.

2.3.4.1 Network description: The Arctic transport system

The main consideration for the transit model was to represent the progress of time and space as the ship sailed through the passage. The Arctic model is further complicated by the transient ice conditions which change with time and place. Changes with respect to time were modelled on a weekly basis, and the passage was geographically divided into nine legs. A week-and-a-leg combination was assumed to have a unique ice condition and speed, dependant on that ice condition. Transit through one of these combinations was considered as an "activity," whose duration was dependent on the length of the leg and speed achieved in that leg during that particular week. However, modeling each of these combinations separately would have resulted in 450 (50*9 = 450) activities, making the model cumbersome. Hence, the VSLAM ARRAY statement was used. By making use of the ARRAY variable, a single activity could be used instead of 450 separate activities. The attributes of this activity were changed every time an entity commenced the activity. The attribute (duration) was defined with the help of an ARRAY variable, which has two subscripts, one representing the row number and the other the column number. The subscripts were changed every time an entity began the activity, thus changing the attribute of the activity. The whole input was visualised as a (50*9) matrix whose rows represented the weeks and columns the legs. Hence, by selecting the ARRAY subscript from this matrix, the activity could be made to represent the transit through a particular leg during a particular week. By representing the transit this way, the ice conditions, the speed, and also the distance could be assigned. The subscripts were modeled by using VSLAM (Global Integer) variables LL [1] and LL [2].

LL [1] represents the row of the ARRAY (or the week) and LL [2] the element of the ARRAY (or the legs). Once the activity was completed, the value of LL [2] was advanced by one, and the entity routed back to the start node. Doing so resulted in the next element or leg being sampled on the subsequent run. The time was checked continuously, and if it exceeded 168 hrs (24*7), then LL [1] was advanced by one which resulted in the sampling from the next row representing the next week. LL [1] was computed continuously by dividing the current time by 168 (24*7) and rounding off to the nearest integer. In this manner, the weeks and the legs were advanced. Once LL [2] reached 10, it implied that the Arctic crossing was over (all the nine legs had been traversed), and the entity was routed to an open-water leg, followed by a port stay at New York (represented by a distribution –Uniform 36, 48). The return was modeled by first traversing the open-water portion and then reducing LL [2] by one for each completion of the activity (LL [2] was reduced from 9 to 0). However, LL [1] was advanced to represent the progress of time. The distances for the legs were varied by another ARRAY with the row number fixed (kept at 51) and the element's subscript equal to LL [2].

All the 144 PDFs used for representing the ice numerals were allotted a Global variable each (XX [n]; where n = 1 to 144). The element of the ARRAY (LL [1], LL [2]) selected before consisted of a numeral equal to [n], thus defining the subscript and the PDF for a leg during a particular time. The Global variables XX[n] were assigned by using the three assign nodes (NORMAL_PDF, BETA_PDF AND TRIAN_PDF). Every time the entity completed an activity, it was routed to these assign nodes so that values of XX[n]s were continuously changed. Thus, a dynamic portrayal of the ice condition (and hence the speed) and distance was obtained. The travel back and forth was continued until a time check indicated 8400 hrs or more. Once the entity had completed 8400 hrs (50 weeks*168), it was routed out of the network and the statistics collected. The time check was made at activity completions only. As a result, the time in the system could have exceeded 8400 hrs. The remaining time to complete the year (or 8760 hrs - 365*24) was considered to be the maintenance time. The runs were repeated 300 times and statistics collected. Three hundred runs were assumed sufficient to stabilise the system, or the simulation was assumed to converge.

2.3.4.2 Network description: The Panama Canal transport system

Modeling the Panama Canal system was much easier as the speed was considered an independent variable. The variation in speed was assumed to be triangularly distributed and the port stays uniformly distributed. The canal transit times were taken from the Panama Canal web site (38). The figures for 2003 were an average of 22.3 hrs for ships without a reservation and 16.8 hrs for ships with a reservation. Hence, a Uniform distribution with a range of 17 to 22.3 hrs was chosen. A spatial grid of 250 nautical Miles was chosen. It was assumed that the sea conditions and hence the speed were likely to remain constant for this interval. The model also incorporated a time check at the end of this 250 NM interval, and the entity was routed out of the system if the simulation time exceeded 8640(360*24), thereby making it possible to improve the accuracy of the round trip estimate. The method involved modeling an activity of distance 250 NM and rerouting the entity again and again until the required total distance was obtained. Thus, the Pacific leg with a distance of 7682 NM (nautical mile=1852 Meters) was modelled by routing the entity 30 times through a 250 NM leg and completing the remaining distance in a single 182 NM leg instead of representing a single leg with a distance of 7682 NM. The networks and VSLAM statements are presented in Appendix 9.After modelling the two transits, various alternatives were incorporated and the models modified. The simulations were run, and the multiple-run summary statistics were collected. The output of the simulation is analysed in the next section.

2.4 Output analysis of the transit model

The initial version was aimed at debugging and also at calculating the average speeds on a monthly basis to determine the seasonal effect on speeds. Only a CAC3 ship was considered, and one-way west-to-east transit was modeled. The results are analysed below.

2.4.1 Simulation result: Monthly average transit speeds

It was observed that the speeds were almost the same throughout the year, with minor variations in May and December. The drop in May could have been due to the consolidation of ice reaching its maximum in May. The December regime could have been the result of the tough conditions encountered in Lancaster Sound due to the freeze-up of residual multi-year ice from the upper Arctic, which cannot be transported down Baffin Bay. However, the results indicated that for a highly strengthened ship of the CAC3 class, the seasonal influence on speed was marginal. The results are presented in Table 8 and graphically represented in Figure 11. As the speeds were linearly correlated to ice numerals and as an ice numeral of 15 will result in a minimum speed of 16.5 knots (y=0.7*15+6), it can be concluded that, at an average speed greater than 17.5, the average transit numeral was greater than 15. Based on the observation that at an ice numeral above 15, the influence of ice on speed is negligible (14), it could be reasonably concluded that a CAC3 vessel can easily accomplish the transit at any time of the year. However, this conclusion does not take into account the effect of pressure fields likely to present.

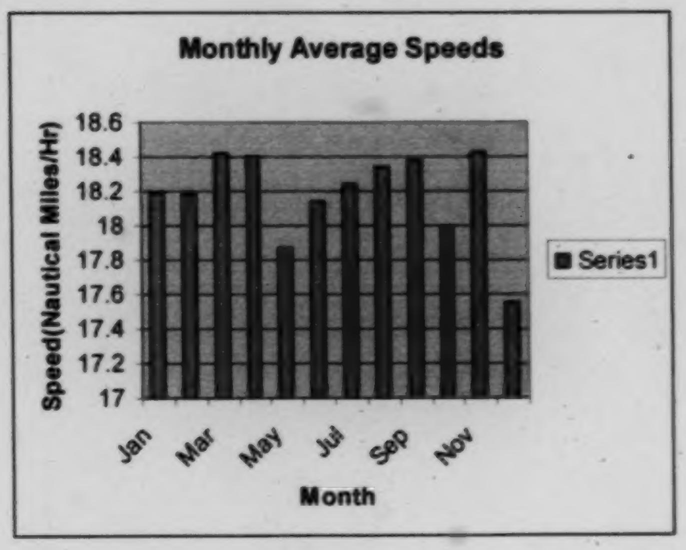


Table 8

Month	Average Speed
Jan	18.192
Feb	18.182
Mar	18.419
Apr	18.405
May	17.868
Jun	18.145
Jul	18.238
Aug	18.34
Sep	18.376
Oct	17.99
Nov	18.43
Dec	17.546

Figure 11: Monthly average speeds of a 20 knots CAC3 Ship.

2.4.2 Simulation results: Round trips per year

The model was then modified to represent the round trips, and statistics were collected for various alternatives. The statistics were for 300 runs and in simulation parlance called "the multi-run summary statistics." The alternatives were investigated and the statistics for "round trips per year" are summarised below in Table 9. The revenue given in the table was calculated from data given in the UNCTAD report "Review of Maritime trade-2003"(24). The revenue for the fast-ship option was calculated by using an average freight rate of $1178 / TEU (Average freight rate for North America – Asia Trade), for a 3000 TEU ship. The revenue for the slow-ship option was calculated by assuming a bulk trip charter rate of $30 /Ton for a 60,000 ton ship.

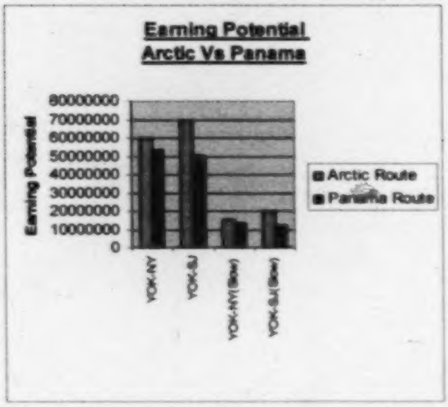


Figure 12: Earning potential for various alternatives.

From the revenue data it is evident that the Yokohama-to-St. John's fast-ship option through the Arctic has a huge economic advantage over the competing alternatives. The differential revenue of $18.8 million over the Panama Canal alternative is approximately equal to the additional investment required for a ship with ice-breaking features (assuming $40 million for a bluewater ship and $60 million for an ice-breaking ship). Even the Yokohama-to-New York route through the Arctic has an advantage of $7 million. The slow-ship option provides incremental revenue of $7.5 million in the Yokohama – St. John's run. In view of the lower investment levels and operating cost, this option is still attractive. However, the slow-ship option in the Yokohama-to-New York sector, with incremental revenue of $1.9 Million, is not an attractive proposition because of the risk associated with the venture.

Table 9: Round trips per year and earning potential of various ventures

Ship Type D=safe speed E=linear	Route	Round Trips/year (Mean)	Round Trips/year (Std dev)	Earning Potential ($US)	Differential Earnings ($/Mill)	
					Optimistic (Linear)	Pessimistic (Safe Speed)
Fast Ship Arctic	YOK-NY	8.521	0.111	60226428		
Fast Ship Panama	YOK-NY	7.553	0.017	53384604	6.8	
Fast Ship Arctic	YOK-SJ	9.739	0.134	68835252		
Fast Ship Panama	YOK-SJ	7.083	0.016	50062644	18.8	
Slow Ship Arctic(E)	YOK-NY	5.032	0.073	15096000		
Slow Ship Arctic(D)	YOK-NY	4.458	0.1	13374000		
Slow Ship Panama	YOK-NY	4.403	0.009	13209000	1.9	1.65
Slow Ship Arctic(E)	YOK-SJ	6.603	0.061	19809000		
Slow Ship Arctic(D)	YOK-SJ	5.029	0.117	15087000		
Slow Ship Panama	YOK-SJ	4.105	0.01	12315000	7.5	2.8

The slow-ship alternative was then simulated by using the safe-speed relationship for the ice numerals. The differential revenue was observed to drop further. Despite having attractive differential earning of $ 7.5 million in the Yokohama to St John's route the slow-ship option was not considered due to the following reasons:

- The slow-ship option is used by the bulk solids segment of the market, typically transporting ores, coal, grain, cement, iron briquettes, etc. These cargoes are generally inexpensive and their transit inventory-carrying cost negligible.
- The bulk solid cargoes do not need fast transportation; hence, the shorter route with a higher cargo insurance premium may not be attractive to the shipper.

- The freight rates for these cargoes are highly cyclical and not attractive enough to warrant a higher and riskier investment.
- Speed of transportation is not a marketing advantage for the bulk solid segment.

The results of a simulation study can assumed to be normally distributed because of the large sample size involved. In addition to the "round trips per year," other performance measures obtained from the transit simulation study are summarised in Table 10 below. These parameters were used for working out the cost elements.

Table 10: Results of transit simulation

Ship Type	Route	Open Water		Ice /Canal Water'		Port Stay	
(D=Difficult; E=Easy)		Sailing Time (Hours)		Sailing Time (Hours)		(Hours)	
		(Mean)	(Std Dev)	(Mean)	(Std Dev)	(Mean)	(Std Dev)
Fast Ship Arctic	YOK-NY	4265.5	47.01	3454.41	51.85	704.95	22.86
Fast Ship Panama	YOK-NY	7721.96	14.68	*294.56*	*5.79*	629.98	13.65
Fast Ship Arctic	YOK-SJ	3652.44	52.16	3975.83	39.22	798.53	17.11
Fast Ship Panama	YOK-SJ	7783.83	14.31	*275.39*	*5.99*	587.35	12.12
Slow Ship Arctic(E)	YOK-NY	4511.31	106.26	3591.29	82.96	385.36	19.65
Slow Ship Panama	YOK-NY	8142.83	11.99	*172.94*	*7.92*	335.62	9.99
Slow Ship Arctic(E)	YOK-SJ	3836.69	30.56	4123.19	41.01	461.49	11.14
Slow Ship Panama	YOK-SJ	8159.84	13.62	*156.878*	*4.14*	335.73	10.24
YOK=Yokohama; NY=New York; SJ=St John's; Canal water time applicable for Panama option							

The results of the transit simulation in the form of multiple summary reports are presented in Appendix 10.

2.5 Summary of transit simulation

A simulation experiment using VSLAM to investigate the feasibility of year-round navigation in the Arctic was designed and run. The focus of the experiment was limited to ice as the only major navigational hazard. A slow-ship option with a speed of 11 knots and a fast-ship option with a speed of 20 knots were investigated. The routes up to St John's and New York from Yokohama through the Arctic as well as the Panama Canal were investigated. The investigation was limited to a CAC3 vessel, which was assumed to be capable of accomplishing the task. The main performance measure evaluated was the round trips per year. Based on the results, the following conclusion could be drawn:

- Year-round navigation at competitive speeds is feasible for a CAC 3 ship.
- The slow-speed option is not viable, and hence, further investigation should be restricted to the fast-ship option.
- The route to St. John's offers approximately 150 % extra revenue-generating potential compared to the route up to New York.

The next aim of the study was to determine the economic performance of the options by examining whether the additional revenue projected is sustainable with the increased operating and capital costs. The economic-performance analysis is dealt with in the next section.

3 Simulation of economic performance

This section deals with the simulation of the economic performance of fast-container-ship options through the Arctic and Panama Canal from Yokohama to St. John's/ New York.

3.1 Overview of Economic simulation

When revenues from a venture are unknown and unpredictable, a cash-flow analysis will not yield confident results. Another approach in such a case is to compare the cost elements and rank the competing ventures on the basis of cost. Due to the cyclical nature of the freight market, this approach is commonly used by the shipping industry for investment analysis. The method involves estimating the annual total cost and dividing it by the annual cargo-carrying capacity of the system. The parameter so estimated is called the "required freight rate"(RFR) and is calculated in $ /Ton or $ /TEU.

The RFR was determined by using a spreadsheet-based simulation study. The software used was @Risk student version (31), which comes as an Excel addin.The procedure followed was similar to that for traffic system modeling. The input was modelled first, followed by system modeling, and output analysis. However, in this case, the output analysis was complimented by sensitivity analysis for the major cost components. All three steps are dealt with in the subsequent section.

3.2 Input modelling: Assumptions and concepts

Input into the economic model consists of the costs and the cargo capacity. The latter was worked out from the "round trips per year" computed from the earlier simulation study. Hence, the main task in developing the input model was the estimation of costs. The steps involved are outlined below:

- Pre-modelling assumptions involving mainly the ship's specification were laid out.
- Cost estimates and a stochastic model for these estimates were developed.

Both the steps are discussed in the succeeding sections.

3.2.1 Pre-modelling assumptions: Ship's specifications

The specifications for the bluewater ship (through the Panama Canal) were selected from the MAN B&W technical papers on container ships (12) and are presented in Table 11 below. The typical ship was assumed to have diesel propulsion with thrusters for enhanced manoeuvrability. The consumption at sea and in port was assumed to be heavy fuel oil, with negligible consumption of diesel fuel. The engine was assumed to be a large two-stroke marine diesel working a fixed pitch propeller. Based on this platform, further assumptions were made and will be discussed under the various cost headings.

Table 11: Ship's specification

No of TEUs / DWT (Metric Tons)	3000(37000DW)
Length Overall(Meters)	220
Breadth(Meters)	32.2
Design Draught(Meters)	12.0
Ships Speed(Knots)	22.0
Specified Max Continuous rated power (Including Sea and Engine Margin) SMCR(Kilo Watts)	25200
Power at economic speed of 20 Knots	18900 KW

The ice-class version was assumed to have the same basic dimensions and carry the same quantity of cargo. The additional ice-breaking features were adapted from the study on ice-breaking technology found in reference (15). The propulsion arrangement assumed was twin screw with a total SMCR of 50,400 KW, powered by the same engines as those in the bluewater ship but with two engines and twice the power instead of one engine as in the bluewater ship. Diesel electric propulsion with ducted fixed-pitch propellers and thrusters for manoeuvrability were assumed. The diesel electric arrangement provides flexibility and helps in taking out an engine from the power train while in open water. The ship was assumed to have a conventional bow with an ice-cutting prow and a water-deluge system (a system which throws a water jet ahead of a ship to clear ice). In addition to ice-strengthening required by the rules, the vessel was to have additional steel cladding on the ice-belt region. The vessel was assumed to have an air bubbler system indented to reduce the friction between the hull and the ice. After deciding on the vessel configuration, the costs were estimated. The cost estimate is dealt with in the following sections.

3.2.2 Cost estimation: An overview

All the estimates were in US dollars. The cost estimation for an ice-breaking cargo ship of 20 knots speed, either from the first principles or from market prices, was nearly impossible as this vessel is non-existent and literature on model studies or conceptual design was scanty. Hence, the approach was to estimate the cost elements by using the bluewater ship's costs as datum and to calculate the performance measure at various levels of costs. The cost elements for which such an approach was used were the following:

- Initial capital cost
- Incremental propulsive power requirement for ice-infested waters
- Insurance premium in ice-infested waters. Both the rate and the insured value were selected by using this approach.

Unlike other industries, the transportation industry has assets that are tangible and have high liquidity. The result is additional markets for the assets. Thus, the economics of the shipping industry is influenced by four markets: freight, new-building, second-hand, and demolition (29). The existence of these four markets results in widely fluctuating ship prices, making capital costs, depreciation, and salvage value uncertain. The market prices of assets worth $28 million can fluctuate in the range of $5 to 32 million over a period as short as 5 years (27, 29). The second-hand market is so dynamic that about 1000 deep-sea merchant vessels representing an investment of $20 billion are sold every year, and ships worth tens of millions are traded like sacks of potatoes in a country market (29). To complicate the matter further, an asset may appreciate over a period, making the concept of "depreciation" irrelevant. The salvage value is also market-governed and fluctuates, albeit to a lesser extent. Most players in the industry are focussed on the asset market rather than the freight market, the latter just serving the purpose of meeting the bottom line. Therefore, the industry operates with a thin margin in a highly cyclical freight market, and money is made mostly by trading in assets. All these factors mandate a stochastic analysis of the economic performance, rather than a deterministic cash-flow approach. However, past data associated with economic variables like fuel cost are rather unpredictable or more suitable for trend analysis. Developing a PDF based on historical data would not be representative of the economic variables (16). In other words, the past cannot be used to predict the future for most of these variables. Mulherin et al. (16) suggested assigning an equally likely probability of occurrences, between two discrete ranges, to deal with the market-related variables, so that this study used mainly Uniform distributions with discrete ranges selected from the past data.

Martin Stopford (29) has classified shipping cost as capital, operational, and voyage costs. The voyage cost includes the fuel cost and port and canal dues. The operational cost includes the crew cost, spares, and repair costs. The capital cost includes the cost of capital, depreciation, and salvage price. The Voyage cost is voyage-specific, variable and borne by the charterer. The operational cost is a fixed cost element and borne by the owner. The capital cost is borne by the owner and is the most uncertain of the three. The various cost elements are dealt with separately in the succeeding sections.

3.3 Voyage costs

The voyage-dependent cost consists of the following:

- The fuel cost at sea and in port: the at-sea fuel cost includes the cost of fuel consumed by the main engine and auxiliaries at sea. The in-port fuel cost includes the cost of fuel consumed for the hotel load. The ship is assumed to be gearless and not to be carrying any refrigerated containers; hence, the auxiliaries are assumed to run only for the hotel load
- Canal dues and ice-breaker charges
- Port charges were omitted as they were assumed to be the same for all the competing systems
- The luboil cost including the cost for the cylinder luboil, the main engine luboil, and the auxiliary engine luboil.

The various voyage costs are discussed below:

3.3.1 Voyage costs: Fuel

The power demand for a bluewater ship was assumed to vary within 75% to 90% (or 18900 KW to 22680 KW) of the SMCR. The specific fuel consumption figures for the latest two-stroke marine diesels were adapted from the web sites of the two leading manufacturers (36, 40) and are given in Table 12 below.

Table 12: Specific fuel consumption: Marine two-stroke engines (Note: The pressure figure is the brake mean effective pressure in Bar)

Engine Make & Type	Specific Fuel consumption(g /Kwh)
Sulzer RTA68T	169 at 19.6 Bar / 161 at 13.7 Bar
Sulzer RTA72U	171 at 18.3 bar / 165 at 12.8 Bar
MAN B&W S90MC	167 at 19 Bar / 160 at 15.2 Bar
MAN B&W K90MC	171 at 18 Bar / 164 at 14.4 Bar

Based on the data above, the specific fuel consumption (SFC) was assumed to be uniformly distributed between 160 g/ Kwh and 171 g/ Kwh. Even though the SFC and the power demand change continuously, they were assumed to remain constant throughout one run (i.e. a one-year period). A large number of repetitions of runs will remedy this anomaly and produce results identical to the discrete variations throughout a run. From the sampled SFC and power demand, the fuel consumption for the main engine was calculated. The fuel consumption for the auxiliaries at sea is independent of the propulsion power. An arbitrary figure of 0.1Tons/ hr was assumed for open-ocean passage and added to the main engine's fuel figures. Panama Canal transit was assumed to be completed at part load. Hence, the main engine's fuel consumption was assumed to vary between 2.0 Tons /hr (equivalent to a 50% load of 12600 KW) and 2.8 Tons /hr (equivalent to a 70% load of 17640 KW). 0.1 Tons /hr was again added for the auxiliary power during Panama transit. Auxiliary consumption was assumed to be the same at 0.1 Tons/hr for repair days and port stays.

The fuel cost for a polar ship was worked out in the three different categories discussed below:

(1) For the open-water leg, the power demand, the SFC, and, hence, the consumption were assumed to be the same as those of the bluewater ship (2). For the ice transit, the power demand was sampled from a range of 37800 KW to 50400 KW (equivalent to 150 % to 200% of the bluewater power demand). The consumption for the auxiliaries was kept the same for the port stay and the open-water passage. However, for the Arctic passage, the consumption was increased to 0.2 Tons /hr to account for the operation of the ice-propulsion auxiliaries (the water jet system, the thrusters, and the air bubbler system).

After estimating the quantities, the fuel oil (bunker) price was estimated. This volatile parameter was estimated from the figures given in the web site of *Bunker world* magazine (33). Bunkering was assumed to be at New York for the Arctic option and at Panama for the Panama option. The prices of bunkers at New York and Panama, based on the last six months' figures, are shown in Table 13 below. Barging charges (@ $ 8700 for New York and $ 5250 flat for Panama) were added to the ex-wharf charge to obtain the final figure. After estimating the fuel cost, the canal and ice breaker charges were estimated.

Table 13: Estimate of bunker prices

Port	Bunker price distribution ($/Ton)	Total Bunker price ($/Ton)
New York	Uniform (160,205) (Ex Wharf) + $6.0/Ton(Barging)	Uniform(166,211)
Panama	Uniform (165,195) (Ex Wharf) + $ 3.3/Ton(Barging)	Uniform (168.3,198.3)

3.3.2 Voyage cost: Canal and ice-breaker dues

The Panama Canal charges were estimated as shown in Table 14. The tariff is based on the Panama Canal /Universal measuring system net ton (PC/UMS) which is complicated to calculate because of the limited ship's particulars available. Hence, for the model ship, an approximation was worked out as shown below.

Table 14: Estimation of Panama Canal charges for model ship (38)

A	Deadweight tons given in specifications	37000 Tons
B	Displacement/Deadweight ratio for container ship	1.4
C	Displacement from A & B above	51800 Tons
D	Panama canal Net tons. = 0.56* Displacement Tons(C*0.56)	29000 Tons .
E	Canal Charges 1st 10,000 Tons @$2.96/Ton (2.96*10000)	$ 29600
F	Canal Charges 2nd 10,000 Tons @$2.90/Ton (2.90*10000)	$ 29000
G	Canal Charges remaining Tons @$2.85/Ton (2.85*9000)	$ 25650
H	Tugs	$ 9900
I	Handling lines and Locomotive	$ 6230
J	Reservation @ $ 0.39 / Ton	$ 11310
K	Miscellaneous (Inspection, equipment hire ,security)	$ 1320
L	Total (E to K)	$ 113010

The canal dues are incurred twice every round trip. Hence, to work out the annual expenditure, the dues per trip were multiplied by two times the "round trips per year". The ice-breaker charges were estimated on a $ 500 /hour basis. The product of the resource-utilisation factor for ice-breaker usage and the total simulation time taken from the traffic simulation were used to calculate the hours of ice-breaker usage. The remaining voyage-dependent cost is the lubricating oil costs.

3.3.3 Voyage cost: Luboil

The three main grades of luboil used by a ship are: the cylinder luboil for main engine, the main engine crank case luboil, and the auxiliary engine luboil. They have to be accounted for separately, as their consumption depends on different factors.

The cylinder luboil consumption depends on the power output of the engine. The specific consumption figures for the MAN B&W engine are 0.7-1.1 g/ Kwh or (0.8-1.2Litre/Kwh at a specific gravity 0.9). For the same power, the specific consumption varies with the rate of change of load and the sulphur content. Hence, to obtain the quantity, the sampled power demand was multiplied by the value from the distribution (Uniform (0.8, 1.2)) for the specific luboil consumption.

The main engine crankcase oil is also specified by a specific consumption. However, in practice, the engine seldom consumes crankcase oil. The consumption occurs when oil is changed in bulk. This change involves substantial quantities in the order of 20,000 litres. The change is based on the oil-condition monitoring. Hence, to avoid spikes in the expense account, the industry practice is to account for this consumption on a daily basis according to the operating hours. In this case, the consumption was assumed to be at the rate of 1.5 litres per engine-operating hour. The quantity was worked out by multiplying the sailing hours in open water by 1.5, and sailing hours in ice by 3.0. The extra quantity for sailing in ice was to account for the running of an extra engine.

The auxiliary engine oil consumption was worked out by estimating a consumption of 10 litres per day for 365 days (3650 litres). A fixed annual quantity of oil consumption was assumed for the auxiliary engines, because they will be running continuously every day of the year, irrespective of the vessel being at sea or in port. The current market prices of marine lubricants were not available publicly; hence, an approximate range of $1.6 to $1.8 / litre including barging and taxes was assumed for all the grades. All other lubes and greases were considered as "stores" and not accounted for separately. The operating costs were estimated next.

3.4 Operating costs

The operating costs represent the fixed cost element in running a ship. They do not depend on the sailing hours and have to be incurred even if the ship is laid up. Due to very high overheads in running an international operation like shipping, the industry has successfully adopted the practice of ship management. Ship-management firms are service providers offering technical support, crewing, victualing, stores, and spares for a ship on a fixed cost basis. This segment of the industry operates by taking advantage of the economy of scale, pooling resources to manage a large number of ships belonging to numerous owners and thereby optimising the overheads. A typical company manages around 100 ships of various owners and offers amazingly low management fees for running a ship. A typical owner with a fleet of 5 to 10 ship can never be as competitive as a ship manager. In view of this trend, the operating costs were estimated on the basis of the management fees. The management fees could not be estimated from publicly available literature and hence, were obtained from an industry source directly (6). The various cost elements in this category are the technical management fees, insurance premiums, and dry-docking costs. These cost elements are dealt with in detail in the following section.

3.4.1 Operating cost: Technical management fees

The technical management fee accounts for the following cost elements:

- Crew wages
- Crew victualling
- Crew turnaround expenditure including recruitment charges, disembarkation/embarkation charges and flight fare
- Stores including all ropes and hawsers, sea stores, paints, minor lubes
- Spares including those for major overhauls and breakdowns
- Inspection and survey expenses.

The technical manning cost estimate given by a leading ship manager (6) for a Panamax container ship was $3000 to $3200 per day, irrespective of the operational status of the ship. Hence, for 365 days, the annual management fee was assumed to be uniformly distributed in the range of $1095000 to $1168000 per year. For the Arctic option, the following additional costs were envisaged:

- Additional officers, consisting of one Ice Navigator and one Second Engineer. The costs for them would amount to $225/day (@ $6000 per month) and $125/day (@$3000 per month), respectively. In addition, the deck and the engine-room crews may have to be supplemented by two and one hands, respectively, to meet the additional work load. The cost for them would amount to $125/day (@$600 per month wages). Hence, the total manning cost was assumed to increase by $ 475/day.
- One additional engine would result in additional spares, and the incremental cost was estimated at $500 per day.

Based on the above assumption, the total management fee for the Arctic option was assumed to be in the range of $ 4000 to $ 4200 per day and a distribution; Uniform (1460000, 1533000), was assumed for the annual cost.

The next major operational cost is the dry-docking cost, which is dealt with in the next section.

3.4.2 Operating cost: Dry docking

Ships have to be dry-docked for cleaning and painting the outer underwater hull, inspection of the outer hull, inspection of propellers, renewal of shaft seals and inspection of the rudder. Hull inspection is regulatory and must be carried out every 2 years and not less often than every 36 months. This regulation would result in dry-docking, at least twice in 5 years. One of these dry dockings can be substituted by an underwater inspection by divers and submersibles, but the procedure has not gained much popularity. Hence, two dry dockings every five years were assumed. The dry-docking cost varies widely with the location. Ship owners tend to dry dock at a place along the normal trading route, without diverting the ship. Hence, figures given by the industry expert had a wide range from $ 250,000 to $ 500,000. The steel work for a bluewater ship, especially in its first 15 years of life, will be minimal, and hence, no correction was made for steel work. The figures were narrowed down, and the cost was calculated by sampling from a distribution Uniform (300000, 400000). The sampled value was then multiplied by two and divided by five to obtain the annual figures.

For the Arctic option, dry docking was expected every year. In addition, steel work of 150 tons to 200 Tons was expected due to ice damage. The cost of this steel work was estimated as $800 to $1600 per ton, including material and labour. Thus, the dry-dock cost for the Arctic option was estimated by sampling from distribution Uniform (300000, 400,00) and adding the steel-work cost, which again is the product of two samples from distribution Uniform (800,1600) and Uniform (150,250) representing the quantity and cost of the steel work.

The next operational cost element to be considered was the insurance premiums.

3.4.3 Operational cost: Insurance premiums

Ships are covered by two kinds of insurance, each different in their scope and method of underwriting. They are the Hull & Machinery and the Protection and Indemnity (P&I) policies. Martin Stopford (29) has estimated insurance costs to be in the range of 15% - 40 % of the operating cost of a ship. The Hull and Machinery policy covers damage or loss to hull and machinery and includes a certain amount of pollution liability. The P & I insurance protects the ship owner from third-party liabilities not covered by Hull and Machinery insurance, claims arising from crew injury or death, and cargo claims. The former is offered by marine insurance companies and the latter by P&I clubs formed by groups of owners. The premium for Hull & Machinery insurance depends on the value of the vessel and the owner's claim record. The premium for P& I insurance depends on the owner's claim record, trading area, nationality of the crew, flag of registry, cargo carried, etc (29). The figures given by the Ship Manager (35) for a $ 40 million Panamax ship were $ 140,000/year for Hull & Machinery and $100,000/year for P & I. These costs amount to approximately 17% of the operational cost and are very low compared to the figures given by Martin Stopford (29). Hence, these figures were chosen as the lower value of the range. The distributions assigned for annual insurance costs were Uniform (140000, 210000) for Hull and Machinery and Uniform (100000, 150000) for P & I. The total insurance cost was obtained by adding up the samples from the two distributions. In the case of the Arctic ship, estimating insurance premiums was a grey area. The venture may not even get an underwriter to insure the vessel, unless certain forms of reinsurance or guarantees can be provided at the governmental level to cover pollution damage. A cargo vessel is not likely to have more than 1500 tons of oil while making the crossing and hence does not pose a hazard of the magnitude of an oil tanker. For the sake of analysis, the premiums were kept at a level of 150% above that of a bluewater ship, and the sensitivity to this cost element was checked. The distributions used were the same as that for the bluewater ship. The sampled results were scaled by a scaling factor of 1.5 to obtain the premiums for the Arctic version. The capital cost was analysed next.

3.5 Capital recovery cost

The UNCTAD Review of Maritime trade (24) has given the new building prices of a 2500 TEU container ship for the years 1985 to 2002. The prices varied from $26 million in1985 to $52 million in 1990 and fell to $28 million in 2002. The same figures with minor corrections were assumed for a 3000 TEU ship, since an incremental capacity of 500 TEU would cause only a marginal increase in construction costs. Hence, the distribution Uniform (29, 55)*1000000 was assigned for the capital cost. The $3 million incremental cost was to account for the increased capacity. The capital recovery factor was worked out by using the following relation:

Capital Recovery Factor (CRF) = P*{(i*(1+i) ^n)/ {(1+i) ^n-1},

Where P = Uniform (29, 55); i = Uniform (0.07, 0.11); n = Uniform (25, 26)

To account for the fluctuation in the cost of capital, a range of 7 % to 11 % was assumed for interest rate (i). The average demolition age of a container ship was found to vary from 25 to 26 years (24). Hence a uniform distribution (25, 26) was chosen for project life (n).

No historical data about the new-building prices of CAC3 class ships are available. Mulherin et al. (16) used the ship-hire charges from the freight market in their model to predict the shipping cost. They simulated the ship's speed and obtained its transit hours. The hourly hire charges where then multiplied by the transit hours to obtain the transit cost. On the other hand, the approach of this study was to calculate the total cost and to find the required hire charges (the freight rate). This approach necessitates the estimate of the capital recovery factor to estimate the cost or the RFR. The prices were sampled from the distribution Uniform (29, 55)*1000000 and scaled with factors ranging from 1.1 to 2.0, and then the sensitivity of the RFR to the various levels of the capital requirement was checked. The distributions for the cost of capital (i) and age (n) were kept the same. The salvage value was considered as negligible.

After defining the input parameters, a spreadsheet model was created to analyse the economic viability of the venture. This step or the system modeling is dealt with in the next section.

3.6 System modeling

The important risks associated with the Arctic shipping venture were identified as follows:

- The first risk is in accurately estimating the speeds achievable during the Arctic transit. The probability of safe transit without ice damage or the ship getting beset, and the speeds at which such a transit is feasible. These issues were addressed by the traffic simulation and the risks quantified.

- The second risk result from uncertainty in estimating the initial capital requirement for the polar ship. The higher capital needs stem from the requirement for higher propulsion power and additional strengthening of the hull. Even if the investment cannot be accurately estimated without a preliminary design, the investment at which the venture will become competitive with the bluewater option can be found out.
- The third risk is in estimating insurance premiums for the polar ship. Sailing in Arctic seas exposes a ship to physical damage and pollution risks. This is likely to result in exorbitant insurance premiums. Hence, the premiums at which the venture will be viable will be of interest to potential investors.

The simulation model for economic performance was designed to address the last two issues by analysing the sensitivities of the performance measure (RFR) to these inputs. An Excel spreadsheet model was constructed for using the input variables and relationships mentioned previously. The @Risk addin (31) allows for the entering of distributions in cells instead of values. While making the calculations, the values sampled from the distributions would be used. The calculation would be repeated a large number of times, thus simulating the variability in the input parameters. @ Risk allows for the use of the Monte Carlo (MC) or Latin Hypercube method for sampling. The latter method is claimed to provide a faster convergence of the simulation and to have lesser tendency for crowding in the centre region, and hence, this method was chosen. Simulation was set up for 1000 iterations per run.

The spreadsheet was set up with the scaling factors for the capital and insurance premiums outside the tabulation. This method was used because of the assumption that the price and premiums of an Arctic ship will have a positive and linear correlation with those of a bluewater vessel.

Even though the input parameters vary independently, they have correlations with each other. For example, a higher value for the initial investment has to result in a higher value for the insurance premium. The inputs are distributions, and random sampling can result in a low value for the investment and at the same instance a high value for premium. To avoid such a situation, @ Risk allows correlating input variable with each other. This correlation is user defined; however, the sampling will be independent of the user definitions, and randomness of the inputs will be maintained. Approximate correlations were fed into the @ Risk correlation window, and consistent correlations were calculated by @ Risk. The correlation matrix is presented in Table 15 below.

Table 15: Correlation matrix for cost variables.

	H&M Premium	P&I Premium	New Build Price	Management Fees	Dry Dock cost	Steel work Cost
H&M Premium	1					
P&I Premium	0.2	1				
New Building Price	0.8	0.2	1			
Management Fees	0.000	0	0.2	1		
Dry dock cost	0.000	0	0.6	0	1	
Steel Work Cost	0.000	0	0.2	0	0.2	1

The correlation ratios range from 1 to -1, where 1 represents highest positive correlation.

In addition to the primary performance measure (RFR), the specific cost was also measured. The specific cost was defined as the total cost/total revenue. The purpose and analysis of this performance measure is explained in the output analysis section of this report.

The simulation was initially set up for the Yokohama –St. John's Arctic route and later modified for other routes. The initial runs were carried out by using a scaling factor of 1.5

and 2.0 for the capital requirement and scaling factor 1.5 for insurance premiums. After the initial runs, it was observed that the sensitivities to insurance premiums were negligible, and sensitivity to the capital recovery factor significant; hence, the emphasis was shifted towards analysing the sensitivity to the capital requirement.

The Arctic versions of the model was therefore embellished to carry out sensitivity simulation with scaling factors of 1.1, 1.2, 1.3 and1.4 for the capital cost. The system model is presented in Appendix 11.

The results of this simulation are analysed in the next section.

3.7 Output analysis

The output analyses of the two performance measures are outlined in the following paragraphs. The result of the simulation in the form of a @Risk summary report is presented in Appendix 12.

3.7.1 Output analysis: RFR

The required freight rates (RFRs) obtained for all the options with different scaling factors are presented in Table 16. The results indicate that the Arctic route to eastern Canada is competitive with the bluewater option, even at an incremental capital level of 55%. However, extension of the route to New York does not provide any competitive advantage over the bluewater counterpart. Without the canal charges, the RFR of the Panama option decreases further. In addition, the sensitivities of the RFR to the various inputs were checked, and the results showed similar trends for all the options. The new-building price was the most sensitive input, with sensitivity ranging from 0.6 to 0.85, so that one standard deviation change in the capital investment will cause 0.6 to 0.85 standard deviation changes in the RFR. The next sensitive input was the interest rate, followed by the bunker prices. Other input parameters did not have any significant impact on the RFR.

Table 16: Consolidated economic simulation results: Required freight rate ($ /TEU)

Performance Measure ($/TEU)	Route		Mean $/TEU	+/- 90% Range	
				Low	High
Yokohama-St John's					
RFR(Scale=1.1)	YOK - St John's	Arctic	267.4	233.1	304.9
RFR(Scale=1.2)	YOK - St John's	Arctic	274.7	238.6	314.2
RFR(Scale=1.3)	YOK - St John's	Arctic	281.9	244.1	323.8
RFR(Scale=1.4)	YOK - St John's	Arctic	289.3	249.6	333.6
RFR(Scale=1.5)	YOK - St John's	Arctic	298.7	255.5	344.1
RFR(Scale=2.0)	YOK - St John's	Arctic	335.1	281.4	391.7
RFR(Scale=1.0)	YOK - St John's	Panama	309.6	247.9	376.8
RFR(Scale=1.0)	YOK - St John's (No canal due)	Panama	285.6	228.1	346.5
Yokohama-New York					
RFR(Scale=1.1)	YOK - New York	Arctic	299.1	261.3	339.3
RFR(Scale=1.2)	YOK - New York	Arctic	307.4	267.5	349.9
RFR(Scale=1.3)	YOK - New York	Arctic	315.7	274.1	360.8
RFR(Scale=1.4)	YOK - New York	Arctic	324.1	280.1	371.1
RFR(Scale=1.5)	YOK - New York	Arctic	334.5	287.5	386.07
RFR(Scale=2.0)	YOK - New York	Arctic	376.2	318.1	441.9
RFR(Scale=1.0)	YOK - New York	Panama	291.9	235.9	354.2
RFR(Scale=1.0)	YOK - New York (No canal due)	Panama	268.2	216.96	332.5

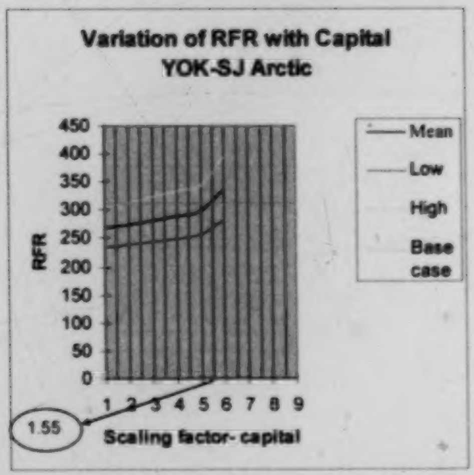


Fig 13: Relationship between the RFR and the capital for Yokohama to St John's option.

The results imply that on the basis of cost, the Arctic route to St. John's is competitive and that to New York is not competitive. However, RFR calculation did not consider the effect of additional revenue generated by the Arctic options, and hence, the effect on the net income and profitability of the whole venture. The calculation also ignores the inventory cost advantage to the customer and the benefits of faster transport as a marketing strategy. As a remedy to the former problem a second performance measure was introduced.

3.7.2 Output analysis: Specific cost:

This measure compares the fraction of revenue spent by various options, on owning and operating the ship (or the cost of goods (services) sold as fraction of revenue). A discounted cash-flow analysis is ideal for ranking investments; however, it has no meaning if the all the cost components and the margin are not known. In this case, the freight rate per TEU for the Trans Pacific trade varied from $800 to $1500 in 2002 (24). The current base rates quoted by Maersk Sea Land Ltd (37) are in the order of

$3500/TEU. Considering the RFR calculated, even a freight of $900/TEU will yield a margin of 200%. This figure is too high for the industry. Hence, it can be assumed that other cost elements need to be considered. The terminal charges, carrier's overheads, cost of intermodal transportation, and customs clearing charge are a few other costs that could be listed. One way to overcome this problem is to find out what portion of the revenue is spent on marine operations and to use this as a comparative measure. For that purpose, the total cost (Voyage+Operational+Capital) was divided by the product of the freight rate and cargo capacity (3000*2*Round trips per year).The freight rate was assigned a distribution of Uniform (721, 1874), based on the variation of the freight rate from $721/ TEU to $1874/TEU (for the Trans-Pacific trade, and for the year 2002) (24). The results give the cost per unit of revenue or the money required to earn one dollar in revenue. The simulation results are presented in Table 17 and graphed in Figure 14 below. The results indicate that the specific cost also follows the trend shown by the RFR. The Yokohama-to-St. John's option is competitive up to an incremental investment level of 50%, whereas the Yokohama–New York option is not cost-competitive even after considering the additional revenue generated.

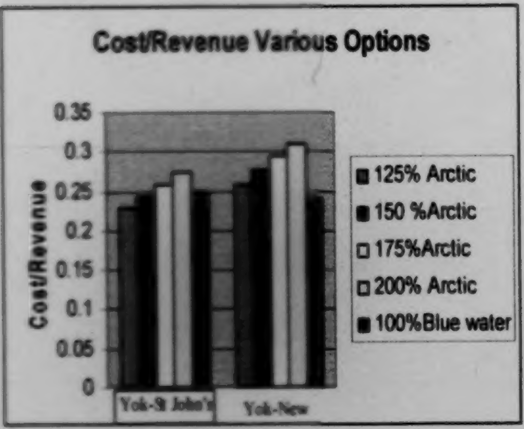


Figure: 14 Comparison of specific costs.

Table 17: Specific cost: Various options.

Investment Level (% of Blue water)	Route		Mean	% of Revenue
	Yokohama-St John's			
125%	YOK - St John's	Arctic	0.229	22.9%
150%	YOK - St John's	Arctic	0.243	24.3%
175%	YOK - St John's	Arctic	0.258	25.8%
200%	YOK - St John's	Arctic	0.273	27.3%
100%	YOK - St John's	Panama	0.25	25.0%
	Yokohama-New York			
125%	YOK - New York	Arctic	0.259	25.9%
150%	YOK - New York	Arctic	0.276	27.6%
175%	YOK - New York	Arctic	0.293	29.3%
200%	YOK - New York	Arctic	0.310	31.0%

The simulation experiments and analysis of the results are summarised in the next section. As well, the model limitations, scope for improvement, and areas of future research are discussed.

4 Conclusion

4.1 Summary:

The Arctic sea route through the ice-infested Canadian Arctic archipelago offers a saving of 3500 nautical miles for a voyage from Japan to Canada's eastern seaboard. The distance saved if the voyage is extended to the US east coast is 1600 nautical miles. The study investigated the feasibility of converting this advantage into a commercial venture by employing advanced ice-breaking cargo ships, which are costlier to acquire and run. The study used simulation techniques to investigate whether a venture employing these ships would be sustainable at the elevated cost levels. The first step was to simulate the transit of such a ship through ice and to determine the speeds and round trips per year achieved. The study was limited to Canadian Arctic Class (CAC3) ships which can be designed with current level of technology. The simulation experiment used historical ice data of the past five years, and it was observed that a CAC3 ship was able to make the year-round transit at reasonable speeds. The chances of the ship getting beset in ice were nil, and the ice-breaker utilisation was minimal. The economic performance of a venture employing 20 knots CAC3 container ship was then simulated by using stochastic inputs for the cost. The "required freight rate" for one TEU was calculated, and it was found that the venture was competitive in the Japan-to-Canada run even at an initial capital requirement of 1.5 times that of a bluewater ship. However, the venture was not competitive for the Japan-to-USA run. The sensitivities of the "required freight rate" were checked for all the routes, and it was observed that the RFR is most sensitive to capital cost, followed by interest rate, power demand, and bunker prices. The ventures were not very sensitive to insurance premiums, management fees, and dry-docking cost/ice-damage repair cost. These conclusions were drawn based on certain assumptions and limitations listed below.

4.2 The model's limitations and scope for further research

The limitations and scope for improving the traffic simulation model are outlined below.

- The model was based on five years of historical data for ice conditions. This time span may be sufficient to represent decadal variation, but not multi-decadal changes. To include these variations, the temporal range of the input data should be extended to ten years and supplemented by representative samples from the previous five decades.
- The model did not consider the effect of the ice-field pressure on ship's speed. This omission was due to the lack of historical data for ice pressures. The model could be improved by considering regimes of concentration above 9/10 as pressure-prone with a 50 % likelihood of occurrence. The ice multipliers could then be modified for such regimes.
- The correlation of the ship's speed and the ice numerals was based on a study of inferior "Type" ships. This information could be supplemented by analysing the transit data for CAC4 ice breakers and Russian ice-breaking ships.
- The model could not be validated due to the lack of real-time transit data for highly ice-strengthened ships equivalent to those of the CAC3 class.
- The model did not consider the effect of continuous ice breaking operation on the thickness of ice. Continuous flow of ice breaker traffic can result in thinner ice along the route and this may ease further operation resulting in better speeds.

The main limitations of the economic model are listed below:

- The propulsion power in ice was assumed to 150% to 200% of the open-water power. This output could be refined by estimating the power demand of the ship in ice from first principles. This improvement is considered important as the RFR has been found to be highly sensitive to the power demand and bunker cost.
- The quantity of steel work due to ice damage was assumed to be 150 to 250 tons annually. This data could be corroborated by analysing the damage data for Arctic supply ships.
- The study was based on the assumption that insurance premiums would be 150% of the bluewater premiums. This estimate could be refined by inputs from marine insurance companies.

5 References

1. Canadian Hydrographic Service. *Canadian Nautical Charts* No: 7000, 7082, 7083, 7573 and 7570.
2. Canadian Hydrographic Service, 1994. *Sailing Direction Arctic Canada*, Vol.1.
3. Canadian Hydrographic Service, 1985. *Sailing Direction Arctic Canada (Eastern Part)*, Vol.2.
4. Canadian Hydrographic Service, 1994. *Sailing Direction Arctic Canada (Western Part*), Vol.3.
5. Canadian Coast Guard.1999. *Ice Navigation in Canadian waters*. Revised Edition.
6. Fleet Management Ltd, Hong Kong. Nagarajan, M.S.Captain. General Manager (Operations), Email correspondence regarding Operational Costs.
7. Holloway, G.and T.Sou. July 2002.*Has Arctic Sea ice rapidly thinned*. Journal of Climate,Vol 15
8. Ice Archives. Canadian Ice Service. Environment Canada. *Various regional Ice charts from January 1999 to December 2003*.
9. Koberle, C. and R. Gerdes. September 2003.*Mechanism determining the variability of Arctic Sea Ice conditions and export*. Journal of Climate, Vol 16
10. Lapp, D., M.Lowings, M. Cameron, D.Wells and D.Hagen. 1986. *Proposed Ice regimes for Arctic Ship Navigation*. Vol 1.Report Prepared by Norland Science and Engineering Ltd, Ottawa and Polar Sea Research Ltd, Lethbridge, Alberta, for Canadian Coast Guard.
11. Leemis, L. 1997.*Seven Habits of highly Successful input Modellers*. Proceedings of the 1997 Winter Simulation Conference.
12. MAN B&W Technical paper. 2004. *Propulsion trends in container vessels*.

13. MAN B&W Technical paper. 2004. *Basic principles of ship propulsion.*

14. McCallum, J., ENFOTEC Technical services Inc, Ottawa and Geoinfo Solution Ltd, Sidney, BC.1996. *Safe Speed in ice –An analysis of Transit Speed and Ice decision Numerals*. Report prepared for Transport Canada.

15. Mulherin, N. D., D. Sodhi and E. Smallidge. (June 1994). *Northern Sea route and Ice breaking Technology* – An overview of current conditions.Reoprt of the US Army, CRREL, Hanover, New Hampshire,USA.

16. Mulherin, N.D., D.T Eppler and D. Sodhi. *A time and cost prediction model for North Sea route shipping.* International Northern Sea route programme (INSROP), Working Paper NO.150-1999.

17. Mulherin, N.D.; D.T. Eppler, T.O. Proshutinsky, A. Y .Proshutinsky, L.D. Farmer and O.P. Smith. *Development and result of Northern Sea route transit Model*. Report of the US Army, CRREL, Hanover, New Hampshire, USA

18. National Oceanic and Atmospheric Administration, National Ocean Survey, United States Department of Commerce. January 1979. *United States Coast Pilot* Volume 9- Pacific and Arctic Coast Alaska - Cape Spencer to Beafort Sea.

19. National Imagery and Mapping agency, Bethesda, Maryland.USA. 2001. Pub 151, *Distances between Ports*, 11th Edition.

20. Nelson B.L and M. Yaministky. 1998. *Input modeling tools for complex Problem.* Proceedings of the1998 Winter Simulation Conference.

21. Polyako, I.V., G.V. Alekseev, R.V. Berkryaev, V.S. Bhatt, R. Colony, M.A. Johnson, V.P. Karklin,P Walsh and A.V.Yulin. June 2003.*Long term Ice variability in Marginal Seas*. Journal of Climate, Vol. 16.

22. Seila, A.F. *Spreadsheet Simulation*. Proceedings of the 2002 Winter Simulation Conference.

23. Transport Canada.1998. TP 12259E. *Arctic Shipping Pollution Prevention regulation Arctic Ice Regime Shipping System Standards (AIRSS).*

24. United Nations Conference on Trade and Development, Geneva. (UNCTAD). 2003. *Review of Maritime Transport.* Report prepared by the UNCTAD Secretariat.

Books

25. Albright S.C., W.L Winston and M.Broadie. 2001. *Practical Management Science,* 2nd Edition. Pacific Groove, California: Duxbury Thomson Learning.

26. Hunt E.C and B.S. Butman. 1985. *Marine Engineering Economics and Cost Analysis,* 1st Edition. Centreville, Maryland. Cornell Maritime Press Inc

27. Kendall L.C and J.J. Buckley. 2001. *The Business of Shipping*, 7th Edition. Centreville, Maryland. Cornell Maritime press Inc.

28. Pritsker, A.B and J.O'Reilly. 1999. *Simulation with Visual Slam and AweSim.*2nd Edition. New York: John Wiley &Sons Inc.

29. Stopford Martin. 1997. *Maritime economics*, 2nd Edition. New York: Routledge.

Software:

30. Bestfit - Student Version. Palisade Corporation Inc

31. @Risk - Student Version. Palissade Corporation Inc

32. VSLAM/Awes - Student version.Symix Systems Inc.

Web sites:

33. Bunker world.(www.bunkerworld.com)

34. Environment Canada. (www.ec.gc.ca)

35. Fleet Management Limited, Hong Kong.(www.fleetship.com)

36. MAN B&W.(www.manbw.com)

37. Maersk Sea Land.(www.maersksealand.com)

38. Panama Canal.(www.pancanal.com)

39. Transport Canada.(www.tc.gc.ca)

40. Wartsila Diesel.(www.wartsila.com)

41. www. worldstats.org

Appendix 1

Understanding the WMO ice EGG Code

The following diagram illustrates an ice EGG (5).Boundaries are required between ice regimes. The basic data covered in an ice EGG is as follows:

- Stages of development or age
- Total Concentration. Concentration is expressed as fraction of the ice in water reported in tenths.
- Partial concentration of a particular ice type; the thickest, the second thickest, and the third thickest are reported in tenths.
- Form or floe size of each ice type.

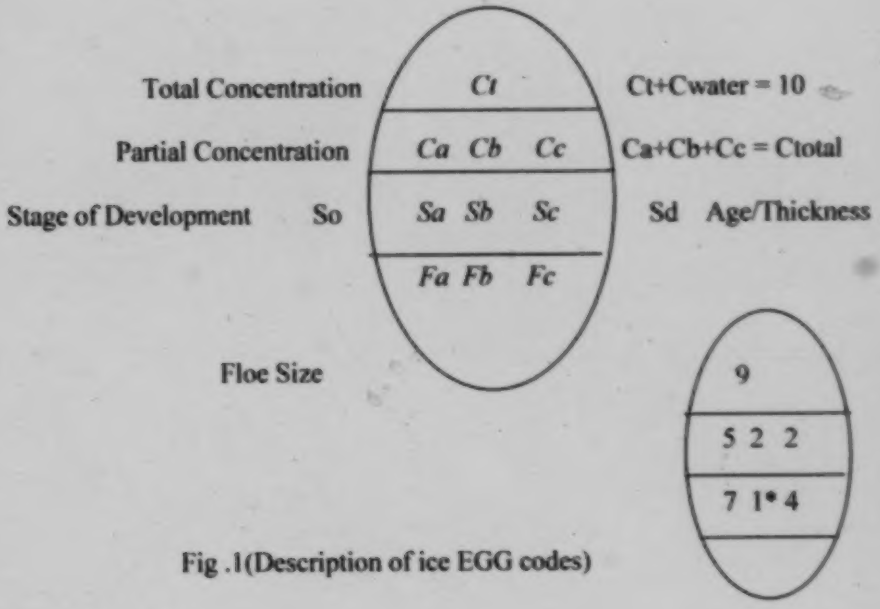

Total Concentration
Ct
Ct+Cwater = 10
Partial Concentration
Ca Cb Cc
Ca+Cb+Cc = Ctotal
Stage of Development
So
Sa Sb Sc
Sd
Age/Thickness
Fa Fb Fc
Floe Size
9
5 2 2
7 1• 4

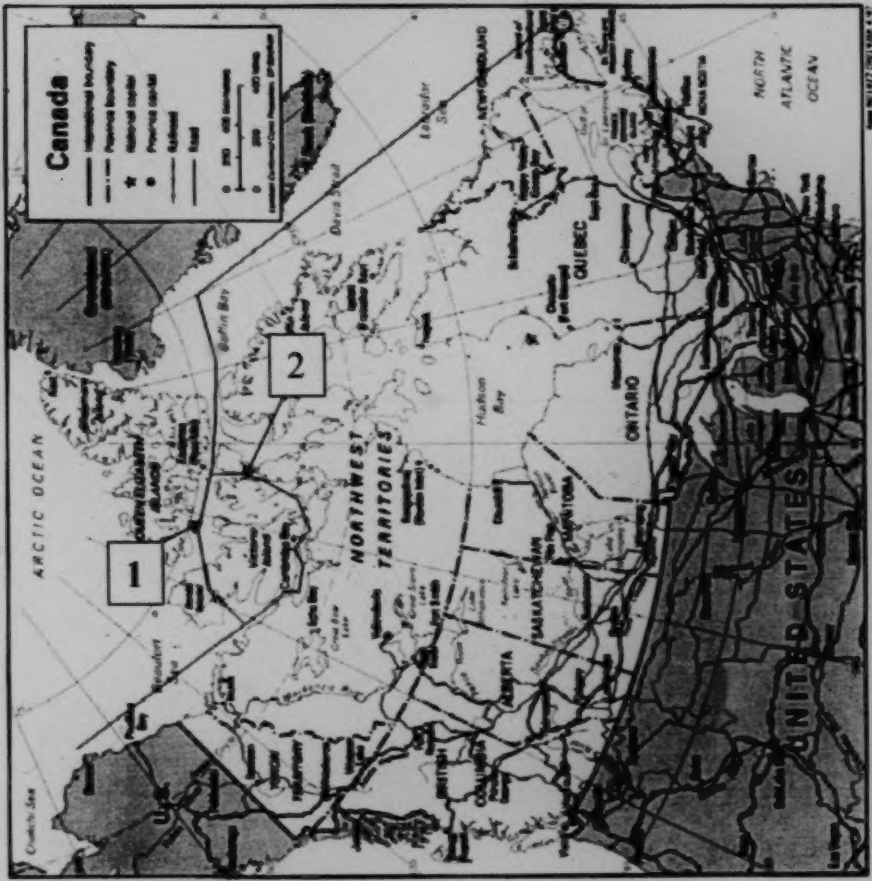
Fig .1(Description of ice EGG codes)

Some salient feature of EGG code is described here.

- A Dot (.) is placed after the numeral for the stages to distinguish between classes of ice. Only one (.) is placed on the 3rd horizontal line of an ice EGG. All figures to the left of the (.) are understood to have a (.) as a part of the code. The stage shown in the example involves ice types 7. , 1. And 4 representing grey ice 10-15cm (4), medium first-year ice 70-120cm (1.) and old ice (7.).
- (So) placed outside the oval indicates a significant trace of a particular ice type. In this case, multi-year ice type (9.) is found in significant traces.
- (Sd) is used rarely when new ice is present during freeze-up or when the remaining ice type concentration is1/10 or more.
- 9+ or 9 tenths is made at the discretion of the forecaster.
- The ice EGG shown as an example indicated 5/10th concentration of 7. (Old ice), 2/10th concentration of medium first-year ice (1.), 2/10th concentration of grey ice (4) and 1/10th concentration of open water. Fully consolidated ice will have a Ct (total concentration) of 10.

Appendix 2

Selected routes


Canada
ARCTIC OCEAN
1
2
Baffin Bay
Davis Strait
Labrador Sea
NEWFOUNDLAND
QUEBEC
ONTARIO
Hudson Bay
NORTHWEST TERRITORIES
MANITOBA
SASKATCHEWAN
ALBERTA
BRITISH COLUMBIA
Beaufort Sea
NORTH ATLANTIC OCEAN
UNITED STATES

1. Via Prince of Wales Straits 2. Via Victoria Straits.

Source[1]

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[1] *Source* www.worldstat.org. *Reproduction for educational purposes permitted by publishers.*

Appendix 3

Calculation of Ice Numerals

(Adapted from *Arctic Shipping Pollution Prevention Regulations*, Arctic Ice Regime Shipping System Standards (AIRSS), Transport Canada Publication TP – 12259E 4TH Edition 1998)

Ice Numeral

The ice numeral is an assessment of an ice regime, in mathematical terms, which is used to determine whether a ship can enter the ice regime. The Ice Numeral, for an ice regime in any Shipping Safety Control Zone or part of a zone, is the sum of the products of the concentration, in tenths, of each ice type and the ice multiplier.

Ice Multipliers

Each ice type in the Ice Multiplier Table shall have the weighting in that column for the respective ship category in column 1.Where the total ice concentration in a regime is 6 tenths or greater and 3/10ths or more of an ice type is deformed by ridges, rubble or hummocking, the weighting for that ice type, taken from the Table, will be decreased by 1, and for 'decayed ice' the weighting may be increased by 1.

Using the system

Important concepts

The Ice Regime System controls navigation on the basis of the actual ice conditions within a given area. An ice regime is a relatively consistent distribution of any mix of ice types, including open water. An ice regime is a region covered with generally consistent ice conditions i.e. the distribution of ice and concentrations does not change very much from point to point in this region. The boundaries between regimes mark major differences in the regional distribution of ice types and concentrations. A regime may be only a few 100's or 1000's of square metres in area or may be many square kilometres in expanse. The determination of the size of a regime depends solely on the distribution of the ice mix. A regime may consist of the broken track behind an icebreaker or other ship, which may give an Ice Numeral considerably different from the unbroken ice, which will be another regime. An ice regime may contain some ice which is beyond the capabilities of a ship to pass through successfully, and much which is not. The decision to enter a given Ice Regime is based on the ability of the vessel to navigate through safely by avoiding the "dangerous" ice. The Ice Regime System provides mariners with a tool to help make this decision. The tool is a simple arithmetical calculation which uses Ice Multipliers to determine an Ice Numeral. If the value of the Ice Numeral is negative, i.e., less than zero, then entry into the ice regime is avoided; a value of zero or greater indicates that entry may be considered.

How the calculation works

Every ice type (including open water) has a numerical value which is dependent on the ice category of the vessel. This number is called an Ice Multiplier (IM). The value of the Ice Multiplier reflects the level of risk or operational constraint that the particular ice type poses to each category of vessel. The ice multiplier table is given below.

Ice Multiplier Table

I	III	IV	V	VI	VII	VIII	IX	X	XI
Ship Type	Open Water	Grey ice	Grey White ice	Thin 1st year 1st stage	Thin 1st year 2nd stage	Med first year	Thick first year	2nd year	Multi year
	OW	G	GW	FY	FY	MFY	TFY	SY	MY
Ice code	1/2	4	3/5	8	7/9	1*	6*/4*	8*	7*/9*
CAC 3	2	2	2	2	2	2	2	1	-1
CAC 4	2	2	2	2	2	2	1	-2	-3
Type A	2	2	2	2	2	1	-1	-3	-4
Type B	2	2	1	1	1	-1	-2	-4	-4
Type C	2	2	1	1	-1	-2	-3	-4	-4
Type D	2	2	1	-1	-1	-2	-3	-4	-4
Type E	2	1	-1	-1	-1	-2	-3	-4	-4

For any ice regime, an Ice Numeral (IN) is calculated by taking the sum of the products of the concentrations of the ice types present (in tenths) in the region and their ice multipliers:

$IN = (C_a \times IM_a) + (C_b \times IM_b) + ...$

where: IN - Ice Numeral

C_a - concentration in tenths of ice type "a"

IM_a - Ice Multiplier for ice type "a" (see Table)

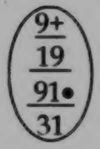
The term on the right-hand side of the equation (a, b, c, etc.) is repeated for as many ice types as may be present, including open water.

The Ice Numeral (IN) is therefore unique to the particular ice regime and the ship operating within its boundaries.

Following are two examples of Ice Numeral calculation.

SAMPLE ICE NUMERAL CALCULATIONS

Example - 1



The Ice Regime above has 1/10th of multi-year ice and 9/10ths of first-year ice.

SHIP CATEGORY - CAC 4

(1× -3) + (9 × 2) i.e. (-3) + (18) = +15 (Ice Numeral)

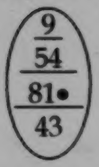
(1, for 1/10th of multi-year ice multiplied by -3, which is the ice multiplier value from the ice multiplier table for a CAC 4 ship in multi-year ice) + (9, which is for 9/10th's of first-year ice multiplied by 2, the ice multiplier value from the ice multiplier table for a CAC 4 ship in first-year ice) gives 15, the Ice Numeral.

SHIP CATEGORY Type B

(1× -4) + (9× -1) i.e. (-4) + (-9) = - 13 (Ice Numeral)

(1, for 1/10th of multi-year ice multiplied by -4, which is the ice-multiplier value from the ice multiplier table for a Type B ship in multi-year ice) + (9, which is for 9/10ths of first-year ice multiplied by -1, the ice-multiplier value from the ice multiplier table for a Type B ship in first year ice) gives -13, the Ice Numeral.

Example – 2



The Ice Regime above has 5/10th second-year ice, 4/10ths first-year medium ice, and 1/10th open water.

SHIP CATEGORY

Type B (5 × -4) + (4 × -1) + (1 × 2) i.e. (-20) + (-4) + (2) = -22 (Ice Numeral)

Type A (5 × -3) + (4 × 1) + (1 × 2) i.e. (-15) + (4) + (2) = -9 (Ice Numeral)

To get an accurate IN, the Ice Multipliers should be adjusted for decayed ice and must be adjusted for ridged ice. The reason is that, a given ice type will be weaker when it is decayed and thicker when ridged.

In all cases, the due caution of the Mariner must be exercised, taking into account such factors as changes in the weather and visibility.

Canadian Classification of Polar ships

(Adapted from Arctic Ice Regime Shipping System - 7 - User Assistance Package)

A new system now exists for determining how the most highly ice-strengthened vessels are classed by Transport Canada, Marine Safety. Four Canadian Arctic Categories (CAC) have now replaced the previous Arctic 1 - Arctic 10 Classes. Details of the new structural classifications are provided in the Transport Canada publication *Equivalent Standards For The Construction Of Arctic Class Ships* - TP 12260 (see Section 8.2); to summarize:

- CAC 1 is seen as an icebreaker which can operate anywhere in the Arctic and can proceed through Multi-Year ice continuously or by ramming according to the owner's performance requirements. A CAC 1 ship is capable of navigation in any ice regime found in the Canadian Arctic and unrestricted ramming of the heaviest ice features (except icebergs or similar Ice formations) for the purpose of ice management. Class CAC 2 is seen as a commercial cargo carrying ship which can trade anywhere in the Arctic, but would take the easiest route. It could proceed through Multi-Year ice continuously or by ramming according to the owner's performance requirements. A CAC 2 ship is capable of navigation in any ice regime found in the Canadian Arctic and ramming of heavy ice feature restricted by its structural capability.

- Class CAC 3 is seen as commercial cargo carrying ship which can trade in the Arctic where ice regimes permit. It would proceed through Multi-Year ice only when it is unavoidable and would do so in a controlled manner usually by ramming. It would be unrestricted in Second and heavy First-Year ice.
- Class CAC 4 is seen as commercial cargo carrying ship which can trade in the Arctic where ice regimes permit. It would be capable of navigating in any thickness of First-Year ice found in the Canadian Arctic, including First-Year ridges. It would avoid Multi-Year ice and when this is not possible it would push or ram at very low speeds.

Vessels CAC 1, 2, 3, and 4 may also be considered suitable escorts, capable of escorting ships of lower classes.

Type ships

The approach that Canada took was to base: Type A, B, C, D, and E vessels on the Finnish-Swedish (Baltic) rules where 'Type A ships can operate in Thick First-Year ice and Type E ships are considered Open Water vessels with no ice strengthening. The Type designation will apply to most of ships working in the Arctic which are less structurally capable than CAC vessels, but have some level of ice strengthening over and above open water requirements.

Appendix 4

Passage planning for Yokohama – New York virtual sailing through Canadian Arctic.

Leg 1: Open Water- Yokohoma to Nome(Alaska)

Nome is chosen as a way point because it is a major harbour prior to the Bering Straits and up to this point it can be assumed that the passage is ice-free for a Canadian Arctic Class ship (CAC). Nome is also listed in the distance table. The distance from Yokohama to Nome is 2696 NM.

Leg 2: Bering Straits; Nome to Point Barrow (71"18.0 ' N; 156" 48.0'W)

Leg 2 -A: The distance from Nome to Barrow, as given in US coast pilot 9 is 566 NM. A portion of this leg until the entrance of Bering Straits can be considered ice-free for a CAC ship. Hence, a distance of 115 NM is eliminated from the distance between Nome to Barrow.

Leg 2-B: The remaining distance of 451 NM (566-115) is assumed to have the same ice condition as that of the Beaufort Sea. This leg covers the west Beaufort Sea and the Bering Strait.

Leg 3: Beaufort Sea -Barrow to Liverpool bay (BATHURST 70' 30" N 129' 00" W):

The course was plotted close to the coast, inshore of the 200 M line. The distance was measured from the 1:5 000000 scale Canadian chart No 7000.The distance was then compared with the distances in the *Sailing Directions Arctic Canada Vol 1 (11).* The measured distance was 567 NM. This leg covers the eastern Beaufort Sea up to Amundsen Gulf.

Leg 4: Amundsen Gulf- Bathurst to Cape Young (69' 06 N; 117' 00 W, 10NM North off C Young):

This leg covers the Amundsen Gulf in total. A straight-line course connecting these points was drawn, and the distance measured was 275 NM.

Leg 5: Coastal straits: Cape Young to Cape Colborne Island (68' 53" N 105' 18"W , 3nm off C. Colborne)

The course follows the recommended track in charts 7082.The distance was measured and compared with the way points mentioned in *Sailing directions Vol 1(11).* The distance measured was 284 NM.This area covers the Dolphin and Union straits, the Coronation Gulf, and the Dease Strait.

Leg 6: Queen Maud Gulf- Cape Colborne to Jenny Lind Island (68' 36" N; 102' 52" W 13 NM of J.L)

The shipping track marked in chart 7083 was followed up to a way point 13 NM off Jenny Lind Island. From there, a north-easterly course is taken into the Victoria strait. This short leg is 58 NM.

Leg 7: Victoria Straits and Larsen Sound- JL Island to Weld Harbour (71' 00 N; 97' 30" W; 19 NM off W Har)

This portion follows the ice breaker channel by keeping Jenny Lind Island, National Geographic Society Islands and King William Island to the starboard and as close as possible to King William Island to take advantage of the favourable ice condition in the south-west portion of the Victoria Straits. The distance measured was 190 NM.The chart used 7083 and 7573.

Leg 8: Franklin Straits and Peel Sound- Weld Harbour to Pressure Point (74' 15" N; 95' 20" W 15 NM off Pr point)

The way point mentioned is approximately midway between the line joining Griffith Island and Pressure Point and lies in the east Barrow Straits. The track followed is through mid-channel of Peel Sound .The total distance is 200 NM.The charts used were 7573 and 7570.

Leg 9: Lancaster Sound: Pressure point to Cape Sherard (74' 20" N; 80' 00"W.18 NM south of Sherard).

The west to east passage lies parallel to 74'N and goes close to Devon Island. The distance measured from chart 7000 was 246 NM.

Leg 10: Baffin Bay: Cape Sherard to Qeqrtarsuaqa (Godhavn- Greenland (70' 00N 56' 20"W.30 NM off Godhavn)

The track crosses the Baffin Bay at the northern end to Upper Navik (Greenland) and continues from there south to Godhavn.The distance measured was 564 NM. The whole Baffin Bay area is covered in this leg. The chart used was Nr.7000

Leg 11 Davis Strait: Godhavn to Labrador Sea (60' 00 N; 54' 00W).

The way point was chosen arbitrarily at the point where the 60th parallel crosses the course to St. John's, NF. The ice line varies a lot in this region, but generally, the region is iceberg infested with, no tough regimes. The distance measured was 595 NM.

Leg 12: Open Water North Atlantic.

The total distance as worked out from the distance table from Labrador Sea ice line to New York is 1868 nm.

Leg 12 A: St. John's to Labrador Sea. The distance between Upper Navik and St. John's is given in the distance table as 1532 NM. Out of this distance, 162 NM (Upper Navik to Godhavn) is included in the Baffin Bay area and 595 NM (Godhavn to Labrador Sea) is included in Davis Strait leg. Hence, open water section is 775 NM.

Leg 12 B: St John's to New York: The distance as given in the distance table is 1093 NM.

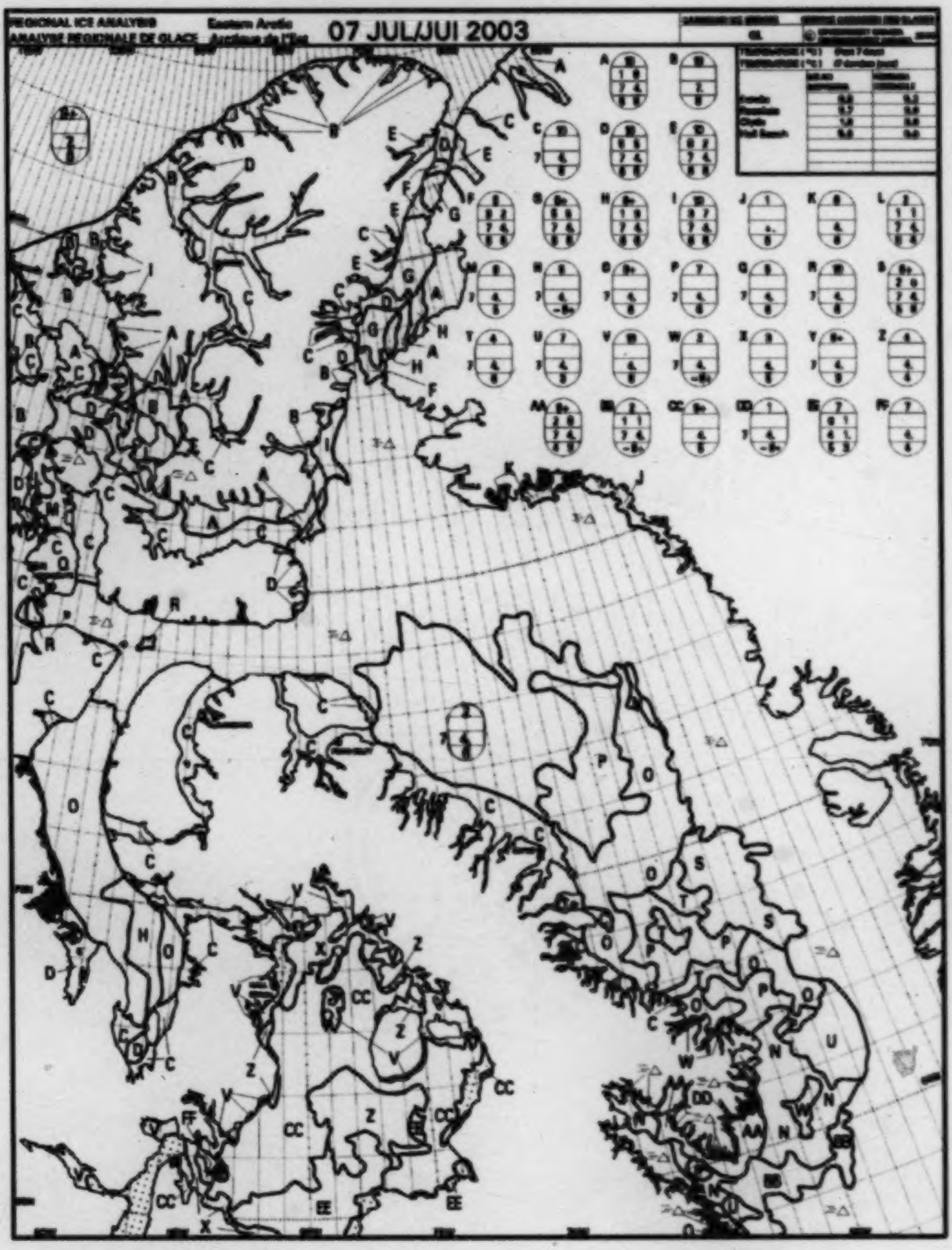
Appendix 5:

Internodal distances and ice numeral quota.

Leg	Leg Name	Way Point From	Way point To	Distance	Allot
1	Open Water	Yokohama	Nome (Alaska)	2696	
2A	Open water	Nome	Bering	115	
2B	Bering straits	Bering	Barrow	451	4
2	Beaufort west	Barrow	Bathurst	567	6
3	Amundsen Gulf	Bathurst	Cape Young	275	2
4	Coastal Straits	Cape Young	Cape Colborne	284	4
5	Queen Maud Gulf	Cape Colborne	Jenny Lind Island	58	2
6	Victoria straits	Jenny Lind Island	Weld Harbour	190	4
7	Peel Sound	Weld Harbour	Pressure Point	200	4
8	Lancaster sound	Pressure Point	Cape Sherard	246	6
9	Baffin bay	Cape Sherard	Godhavn	564	6
10	Davis strait	Godhavn	Labrador Sea	595	6
11	Open water	Labrador Sea	New York	1868	
12	Open Water	Labrador Sea	St John's	775	
13	Prince of Wales				2
14	Melville sound				4
15	Barrow straits				5

Appendix 6 (Sample Ice Chart)

[1]


REGIONAL ICE ANALYSIS
ANALYSE REGIONALE DE GLACE
Eastern Arctic
Arctique de l'Est
07 JUL/JUI 2003

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[1] *Source: Environment Canada web site. Regimes O, P, R, S, U, and W selected for calculation.*

Appendix 6 (Spread Sheet)

Digitisation of Ice chart Sample Spread sheet based on ice chart 2 nd week of July 2003
ICE CHART : Date: 07-Jul-03 Eastern Arctic
EGG CODE Data **Total**
ICE REGIME NO **Partial Concentration(Ca—Cc)** **Conc**

EGG NO	1	1								9	10	***													
EGG NO	2										0														
EGG NO	3									10	10														
EGG NO	4										0														
EGG NO	O	1		9							10														
EGG NO	P	1		7						2	10														
EGG NO	R	1		9							10														
EGG NO	S	2		8							10														
EGG NO	U	1		7						2	10														
EGG NO	W	1		2						7	10														
EGG NO											0														
EGG NO											0														
EGG NO											0														
EGG NO											0														
EGG NO											0														
Ice Type (Sa—Sc)		"7./9."	"8."	"6/4	"1."	"7/9	"8"	"3 / 5"	"4"	"2/1	O	P	R	S	U	W	0	0	0	0	0	1	2	3	4
Type E		-4	-4	-3	-2	-1	-1	-1	1	2	-31	-21	-31	-32	-21	4						14		20	
Type D		-4	-4	-3	-2	-1	-1	1	2	2	-31	-21	-31	-32	-21	4						14		20	
Type C		-4	-4	-3	-2	-1	1	1	2	2	-31	-21	-31	-32	-21	4						14		20	
Type B		-4	-4	-2	-1	1	1	1	2	2	-22	-14	-22	-24	-14	6						14		20	
Type A		-4	-3	-1	1	2	2	2	2	2	-13	-7	-13	-16	-7	8						14		20	
CAC 4		-3	-2	1	2	2	2	2	2	2	6	8	6	2	8	13						15		20	
CAC 3		-1	-1	2	2	2	2	2	2	2	17	17	17	14	17	17						17		20	

Lancaster Sound
R,1,1,1
Baffin Bay
1,1,1,W,P
Davis Straits
O,S,U,1,1,1

Eastern Arctic

		R	1	1	1	1	1	10	W	1	1	1	1	1	10	1	S	U	1	1	1	10	10	10
Type E		-31	14	14	14	14	14	"	4	14	14	14	14	14	"	14	-32	-21	14	14	14	"	"	"
Type D		-31	14	14	14	14	14	"	4	14	14	14	14	14	"	14	-32	-21	14	14	14	"	"	"
Type C		-31	14	14	14	14	14	"	4	14	14	14	14	14	"	14	-32	-21	14	14	14	"	"	"
Type B		-22	14	14	14	14	14	"	6	14	14	14	14	14	"	14	-24	-14	14	14	14	"	"	"
Type A		-13	14	14	14	14	14	"	8	14	14	14	14	14	"	14	-16	-7	14	14	14	"	"	"
CAC 4		6	15	15	15	15	15	"	13	15	15	15	15	15	"	15	2	8	15	15	15	"	"	"
CAC 3		17	17	17	17	17	17	"	17	17	17	17	17	17	"	17	14	17	17	17	17	"	"	"

Appendix 7 (CAC3 Ice Numerals)

ICE NUMERALS-Canadian Arctic Ice Regime Shipping System(AIRSS)

Source : (Calculated from Canadian Ice services regional ice charts online Archives)
Ship type: **CAC3**
Region: **WEST ARCTIC**

Dates	Beaufort Sea						Amund Gulf		Coastal Straits				Queen Maud		Victoria Strait				Peel Sound			
01JAN99	17	20	20	20	20	17 "	17	20 "	20	20	17	17 "	17	17 "	17	17	8	8 "	20	20	17	17
01JAN00	14	20	5	17	17	17 "	17	17 "	20	20	17	17 "	17	17 "	8	17	17	17 "	17	17	17	17
01JAN01	17	17	17	17	17	8 "	17	17 "	20	20	20	20 "	17	17 "	17	17	17	17 "	17	17	17	17
01JAN02	11	11	11	17	17	17 "	17	17 "	17	17	17	17 "	11	17 "	17	17	17	17 "	17	11	17	17
01JAN03	17	17	17	17	17	17 "	17	17 "	17	17	17	17 "	17	17 "	17	17	5	5 "	17	17	17	17
01FEB99	14	17	17	17	17	17 "	17	17 "	17	17	17	17 "	17	17 "	17	8	8	17 "	17	17	20	20
01FEB00	8	8	17	17	17	20 "	17	17 "	20	20	17	17 "	17	8 "	8	17	17	17 "	17	17	17	17
01FEB01	5	17	17	17	17	17 "	17	17 "	20	20	20	20 "	17	17 "	17	17	17	17 "	17	17	17	14
01FEB02	11	11	17	17	17	17 "	17	17 "	20	20	20	17 "	17	11 "	17	17	17	17 "	11	2	17	17
01FEB03	17	17	17	17	17	17 "	17	17 "	17	17	17	17 "	17	17 "	17	5	5	17 "	17	17	17	17
01MAR99	14	17	17	17	17	17 "	17	17 "	17	17	17	17 "	17	17 "	17	8	8	17 "	17	17	17	20
01MAR00	14	14	20	17	17	5 "	20	20 "	20	20	20	17 "	8	20 "	8	17	17	17 "	17	17	17	17
01MAR01	17	17	17	17	17	17 "	17	17 "	20	20	20	17 "	17	17 "	17	17	17	17 "	17	17	17	17
01MAR02	17	11	17	17	20	17 "	17	17 "	20	20	20	17 "	11	17 "	17	17	17	17 "	17	11	2	17
01MAR03	17	17	17	17	17	17 "	17	17 "	17	17	17	17 "	17	17 "	5	5	17	17 "	17	17	17	17
01APR99	17	8	8	17	17	17 "	17	17 "	17	17	17	17 "	17	17 "	17	8	8	17 "	17	17	17	20
01APR00	17	20	5	14	17	17 "	20	20 "	20	20	20	17 "	17	8 "	8	17	17	17 "	17	17	17	17
01APR01	17	2	17	11	11	11 "	11	17 "	20	20	20	11 "	11	11 "	11	11	11	11 "	11	11	11	11
01APR02	17	17	17	17	17	17 "	17	17 "	20	20	20	17 "	17	11 "	17	17	17	17 "	17	11	2	17
01APR03	17	17	17	17	17	17 "	17	17 "	17	17	17	17 "	17	17 "	5	5	17	17 "	17	17	17	17
01DEC99	17	17	17	17	17	17 "	17	17 "	17	17	14	17 "	17	-4 "	8	17	17	17 "	17	17	17	17
01DEC00	17	17	17	17	17	17 "	17	17 "	20	20	20	17 "	17	17 "	17	17	17	17 "	17	17	17	17
01DEC01						"	" "	"				"		"				"				
01DEC02	17	17	17	17	17	17 "	17	17 "	17	17	17	17 "	17	17 "	17	5	5	17 "	17	17	17	17
01DEC03	17	17	17	17	17	17 "	17	17 "	17	20	17	20 "	17	17 "	17	17	11	-1 "	17	17	11	2

ICE NUMERALS-Canadian Arctic Ice Regime Shipping System(AIRSS)

Source : (Calculated from Canadian Ice services regional ice charts online Archives)
Ship type: **CAC3**
Region: **WEST ARCTIC**

Dates	Beaufort Sea						Amund Gulf		Coastal Straits				Queen Maud		Victoria Strait				Peel Sound			
01MAY99	17	17	17	17	2	8 "	17	17 "	17	17	17	17 "	17	17 "	17	8	17	17 "	17	17	17	20
01MAY00	14	8	20	17	17	17 "	20	20 "	20	20	17	17 "	8	17 "	8	17	17	17 "	17	17	17	17
01MAY01	11	17	17	17	17	11 "	17	17 "	20	20	20	17 "	17	17 "	17	17	17	17 "	17	17	17	17
01MAY02	17	17	17	17	17	17 "	17	17 "	20	20	20	17 "	11	17 "	17	17	17	17 "	11	2	17	17
01MAY03	17	17	17	17	17	17 "	17	17 "	17	17	17	17 "	17	17 "	5	5	17	17 "	17	17	17	17
02MAY99	17	17	17	17	17	2 "	17	20 "	17	17	17	17 "	17	17 "	17	8	8	17 "	17	17	17	20
02MAY00	14	20	8	17	17	17 "	20	20 "	20	20	17	17 "	20	8 "	8	17	17	17 "	17	17	17	17
02MAY01	11	11	11	17	17	17 "	17	17 "	17	20	20	20 "	17	17 "	17	17	17	17 "	17	17	17	17
02MAY02	17	17	17	17	17	17 "	17	17 "	20	20	20	17 "	11	17 "	17	17	17	17 "	11	2	17	17
02MAY03	17	17	17	17	17	17 "	17	17 "	17	17	17	17 "	17	17 "	5	5	17	17 "	17	17	17	17

ICE NUMERALS-Canadian Arctic Ice Regime Shipping System(AIRSS)

Source : (Calculated from Canadian Ice services regional ice charts online Archives)

Ship type: CAC3

Region: WEST ARCTIC

Dates	Beaufort Sea						Amund Gulf		Coastal Straits				Queen Maud		Victoria Strait				Peel Sound			
01JUN99	17	17	17	20	17	17 "	20	17 "	17	17	17	17 "	17	17 "	17	17	8	8 "	17	17	17	17
01JUN00	14	8	20	17	17	17 "	20	20 "	20	20	17	17 "	17	17 "	8	17	17	17 "	17	17	17	17
01JUN01	11	11	17	17	17	17 "	17	17 "	20	20	20	20 "	17	17 "	17	17	17	17 "	17	17	17	17
01JUN02	20	17	17	17	17	17 "	17	17 "	20	20	20	20 "	17	11 "	17	17	17	17 "	11	11	17	17
01JUN03	20	20	20	17	17	17 "	17	17 "	17	17	17	17 "	17	17 "	5	17	5	17 "	17	17	17	17
02JUN99	17	17	17	20	17	17 "	20	17 "	17	17	17	17 "	17	17 "	17	17	8	8 "	17	17	17	17
02JUN00	14	20	8	17	17	17 "	20	20 "	17	20	17	17 "	20	17 "	8	17	17	17 "	17	17	17	17
02JUN01	11	17	17	17	17	-4 "	17	17 "	20	20	20	17 "	17	17 "	17	17	17	17 "	17	17	17	17
02JUN02	17	17	17	20	17	17 "	17	17 "	20	20	20	17 "	17	11 "	17	17	17	17 "	11	11	17	17
02JUN03	20	20	20	17	17	17 "	17	17 "	17	17	17	17 "	17	17 "	5	5	17	17 "	17	17	17	17
03JUN99	17	17	17	17	17	17 "	20	20 "	17	17	17	17 "	17	17 "	17	17	8	8 "	17	17	17	20
03JUN00	14	8	20	17	17	17 "	17	20 "	20	20	17	17 "	20	17 "	8	17	17	17 "	17	17	17	17
03JUN01	11	17	17	17	17	17 "	17	20 "	20	20	20	17 "	17	17 "	17	17	17	17 "	17	17	17	17
03JUN02	17	17	17	17	17	17 "	17	17 "	17	20	20	17 "	17	11 "	17	17	17	17 "	11	11	17	17
03JUN03	20	20	17	20	17	17 "	17	17 "	17	17	17	17 "	17	17 "	5	5	5	17 "	17	17	17	17
04JUN99	17	17	17	20	17	17 "	20	17 "	17	17	17	17 "	17	17 "	17	17	8	8 "	17	17	17	17
04JUN00	14	20	8	17	17	17 "	20	20 "	20	20	20	17 "	17	20 "	8	17	17	17 "	17	17	17	17
04JUN01																						
04JUN02	17	17	17	17	17	17 "	17	17 "	17	20	20	17 "	17	11 "	17	17	17	17 "	11	11	2	17
04JUN03	17	17	17	17	17	20 "	20	17 "	17	17	17	17 "	17	17 "	5	5	5	17 "	17	17	17	17

ICE NUMERALS-Canadian Arctic Ice Regime Shipping System(AIRSS)

Source : (Calculated from Canadian Ice services regional ice charts online Archives)
Ship type: CAC3
Region: WEST ARCTIC

Dates	Beaufort Sea						Amund Gulf		Coastal Straits				Queen Maud		Victoria Strait				Peel Sound			
01JUL99	17	17	17	17	17	17 "	20	20 "	17	17	17	17 "	17	17 "	17	17	8	8 "	17	17	17	17
01JUL00	14	8	17	20	17	17 "	17	20 "	20	20	14	20 "	20	8 "	8	20	20	20 "	20	20	20	20
01JUL01	11	17	17	17	17	17 "	17	20 "	17	20	20	20 "	17	17 "	17	17	17	17 "	17	17	17	17
01JUL02	17	17	17	17	17	17 "	17	17 "	20	20	20	20 "	17	11 "	17	17	17	17 "	11	11	17	17
01JUL03	17	17	17	20	17	17 "	17	17 "	17	17	17	17 "	17	17 "	17	17	5	5 "	17	17	17	17
02JUL99	20	20	20	20	17	17 "	20	20 "	20	17	17	17 "	17	17 "	17	8	8	8 "	17	17	17	17
02JUL00	14	8	17	17	17	17 "	20	20 "	20	20	14	17 "	17	20 "	8	17	17	17 "	17	17	17	17
02JUL01	11	17	17	17	17	17 "	20	20 "	20	20	20	20 "	17	17 "	17	17	17	17 "	17	17	17	17
02JUL02	17	17	17	17	17	17 "	17	17 "	17	17	17	17 "	17	11 "	17	17	17	17 "	11	17	2	17
02JUL03	17	17	20	17	17	17 "	17	17 "	17	17	17	17 "	17	17 "	17	17	5	5 "	17	17	17	17
03JUL99	17	20	20	17	20	20 "	20	20 "	20	20	17	17 "	17	17 "	17	8	8	8 "	17	17	17	17
03JUL00	14	14	17	17	14	14 "	20	20 "	20	20	20	20 "	20	17 "	8	17	17	17 "	17	17	17	17
03JUL01	11	17	17	17	17	17 "	20	20 "	20	20	17	17 "	17	17 "	17	17	17	17 "	17	17	17	17
03JUL02	17	20	20	17	17	20 "	20	20 "	17	17	20	17 "	17	11 "	20	17	17	17 "	20	11	11	11
03JUL03	20	17	17	17	17	20 "	20	17 "	17	17	20	17 "	17	17 "	17	5	5	5 "	17	17	17	17
04JUL99	17	17	20	14	14	17 "	20	20 "	20	20	20	17 "	20	20 "	17	17	17	14 "	17	17	17	17
04JUL00	8	14	17	14	17	17 "	17	20 "	20	20	17	17 "	17	17 "	8	17	17	17 "	17	17	17	17
04JUL01	11	17	17	17	20	17 "	20	20 "	20	20	17	20 "	17	17 "	17	17	17	17 "	17	17	17	17
04JUL02	17	17	17	14	17	17 "	17	14 "	17	20	17	20 "	14	17 "	17	17	17	17 "	17	11	5	17
04JUL03	17	20	17	17	17	17 "	20	17 "	17	20	17	17 "	17	17 "	14	5	5	5 "	17	17	17	17
05JUL00	20	14	17	17	17	17 "	17	17 "	17	17	20	17 "	14	14 "	17	17	20	20 "	17	17	20	20
05JUL01	8	17	17	17	20	17 "	20	20 "	20	20	20	20 "	17	20 "	17	17	17	17 "	17	17	17	17

ICE NUMERALS-Canadian Arctic Ice Regime Shipping System(AIRSS)

Source : (Calculated from Canadian Ice services regional ice charts online Archives)

Ship type: **CAC3**

Region: **WEST ARCTIC**

Dates	Beaufort Sea						Amund Gulf		Coastal Straits				Queen Maud		Victoria Strait				Peel Sound			
01AUG99	20	17	17	20	20	17 "	20	20 "	20	20	20	20 "	20	20 "	17	17	14	17 "	17	17	17	17
01AUG00	20	17	17	17	17	14 "	20	20 "	20	20	20	20 "	20	17 "	8	17	17	17 "	17	17	17	17
01AUG01	8	17	17	20	17	14 "	20	20 "	20	20	20	20 "	20	20 "	17	17	17	17 "	17	17	17	17
01AUG02	17	17	17	17	8	17 "	17	17 "	14	17	20	20 "	17	20 "	17	14	17	17 "	17	14	14	14
01AUG03	17	20	17	17	20	11 "	20	20 "	20	20	20	20 "	20	17 "	11	11	5	20 "	20	17	17	17
02AUG99	20	17	17	17	17	20 "	20	20 "	20	20	20	20 "	20	17 "	17	17	17	14 "	17	17	17	20
02AUG00	17	17	17	17	17	17 "	20	20 "	20	20	20	20 "	20	20 "	17	17	17	17 "	20	17	17	20
02AUG01	20	17	14	8	17	17 "	20	20 "	20	20	20	20 "	20	20 "	17	17	17	17 "	17	20	20	20
02AUG02	14	14	17	17	17	11 "	17	20 "	20	20	17	20 "	20	20 "	17	17	11	17 "	20	14	17	17
02AUG03	20	20	17	11	2	20 "	20	20 "	20	20	20	20 "	20	20 "	20	17	17	17 "	17	17	20	17
03AUG99	17	20	17	17	20	20 "	20	20 "	20	20	20	20 "	20	20 "	17	17	17	14 "	20	17	20	17
03AUG00	20	17	17	17	17	17 "	20	20 "	20	20	20	20 "	20	20 "	20	20	20	20 "	20	20	20	20
03AUG01	-4	5	-1	20	-7	14 "	20	20 "	20	20	20	20 "	20	20 "	14	14	11	17 "	17	14	11	20
03AUG02	17	17	17	17	2	14 "	20	20 "	20	20	20	20 "	20	20 "	17	17	17	17 "	17	17	20	17
03AUG03	20	17	20	17	5	20 "	20	20 "	20	20	20	20 "	20	20 "	17	17	17	17 "	17	17	14	8
04AUG99	17	20	20	20	20	20 "	20	20 "	20	20	20	20 "	20	20 "	17	14	17	14 "	20	20	20	20
04AUG00	20	17	17	20	20	17 "	20	20 "	20	20	20	20 "	20	20 "	17	20	20	20 "	20	20	20	20
04AUG01	20	8	5	20	14	20 "	20	20 "	20	20	20	20 "	20	20 "	14	14	11	17 "	14	17	8	14
04AUG02	20	17	17	17	17	17 "	20	17 "	20	20	20	20 "	20	20 "	20	17	17	17 "	17	17	17	20
04AUG03	17	20	17	11	2	17 "	20	20 "	20	17	20	20 "	20	20 "	20	17	17	17 "	17	17	17	8
05AUG99	20	20	20	20	20	20 "	20	20 "	20	20	20	20 "	20	20 "	14	17	17	20 "	20	20	20	20

ICE NUMERALS-Canadian Arctic Ice Regime Shipping System(AIRSS)

Source :	(Calculated from Canadian Ice services regional ice charts online Archives)
Ship type:	**CAC3**
Region:	**WEST ARCTIC**

Dates	Beaufort Sea						Amund Gulf		Coastal Straits				Queen Maud		Victoria Strait				Peel Sound			
01SEP99	20	20	20	20	14	14 "	20	20 "	20	20	20	20 "	20	20 "	14	14	20	20 "	20	20	17	20
01SEP00	20	20	17	20	20	20 "	20	20 "	20	20	20	20 "	20	20 "	20	20	5	20 "	20	20	20	20
01SEP01	20	14	20	20	14	20 "	20	20 "	20	20	20	20 "	20	20 "	17	17	11	20 "	17	20	20	17
01SEP02	20	17	17	17	17	17 "	20	11 "	17	20	20	20 "	20	20 "	20	17	20	20 "	17	17	17	17
01SEP03	20	20	17	20	17	20 "	20	20 "	20	17	20	20 "	20	20 "	20	17	17	17 "	17	14	11	8
02SEP99	14	20	20	20	20	20 "	20	20 "	20	20	20	20 "	20	20 "	17	14	17	20 "	20	20	20	17
02SEP00	17	20	20	20	20	20 "	20	20 "	20	20	20	20 "	20	20 "	20	20	20	20 "	20	20	20	20
02SEP01	20	14	20	20	20	20 "	20	20 "	20	20	20	20 "	20	20 "	20	5	11	17 "	20	20	14	17
02SEP02	20	20	17	17	11	17 "	17	20 "	20	20	20	20 "	20	20 "	20	20	20	20 "	20	20	14	14
02SEP03	20	20	17	14	11	20 "	20	20 "	20	20	20	20 "	20	20 "	17	17	17	17 "	17	17	14	14
03SEP99	20	20	20	20	17	20 "	20	20 "	20	20	20	20 "	20	20 "	20	17	17	20 "	20	20	20	20
03SEP00	8	8	20	20	20	20 "	20	20 "	20	20	20	20 "	20	20 "	20	20	20	20 "	20	20	20	20
03SEP01	20	20	17	20	20	20 "	20	20 "	20	20	20	20 "	20	14 "	11	8	8	14 "	20	17	5	11
03SEP02	20	20	17	20	20	20 "	20	20 "	20	20	20	20 "	20	20 "	20	20	20	20 "	20	20	20	11
03SEP03	20	20	17	-1	14	17 "	20	20 "	20	20	20	20 "	20	20 "	17	20	17	20 "	17	17	17	8
04SEP99	20	20	20	20	20	20 "	20	20 "	20	20	20	20 "	20	20 "	20	20	20	17 "	20	20	17	20
04SEP00	20	20	20	20	20	17 "	20	20 "	20	20	20	20 "	20	20 "	14	2	20	20 "	20	20	20	20
04SEP01	20	20	20	20	20	17 "	20	20 "	20	20	20	20 "	20	20 "	14	2	20	20 "	20	20	20	20
04SEP02	20	20	20	20	20	20 "	20	20 "	20	20	20	20 "	20	20 "	20	20	20	20 "	20	20	20	17
04SEP03	20	20	14	8	14	20 "	20	20 "	20	20	20	20 "	20	20 "	17	14	20	20 "	14	5	17	-4
05SEP02	20	20	20	20	20	20 "	20	20 "	20	20	20	20 "	20	20 "	20	20	20	20 "	20	17	14	17
05SEP03	20	20	-1	14	14	17 "	20	20 "	20	20	20	20 "	20	20 "	17	14	20	20 "	17	14	14	-1

ICE NUMERALS-Canadian Arctic Ice Regime Shipping System(AIRSS)

Source : (Calculated from Canadian Ice services regional ice charts online Archives)

Ship type: CAC3

Region: WEST ARCTIC

Dates	Beaufort Sea						Amund Gulf		Coastal Straits				Queen Maud		Victoria Strait				Peel Sound			
01OCT99	20	20	20	17	20	20 "	20	20 "	20	20	20	20 "	20	20 "	11	11	17	17 "	17	17	17	17
01OCT00	20	20	17	20	17	17 "	20	20 "	20	20	20	20 "	20	20 "	20	17	17	17 "	20	17	17	17
01OCT01	20	14	17	14	17	20 "	20	20 "	20	20	20	20 "	20	20 "	20	20	20	20 "	20	20	14	20
01OCT02	20	20	20	17	20	20 "	20	20 "	20	20	20	20 "	20	20 "	17	17	17	17 "	17	17	17	14
10OCT03	20	20	14	14	14	20 "	20	20 "	20	20	20	20 "	20	20 "	17	17	17	14 "	8	2	2	14
02OCT99	20	20	20	20	5	17 "	20	20 "	20	20	20	20 "	17	11 "	11	17	17	17 "	17	17	17	17
02OCT00	17	17	17	17	17	2 "	20	20 "	20	20	20	20 "	20	20 "	17	17	17	17 "	17	17	17	17
02OCT01	14	14	20	17	14	20 "	20	20 "	20	20	20	20 "	20	20 "	20	8	17	17 "	17	17	8	17
02OCT02	20	20	17	17	17	20 "	17	17 "	17	20	20	20 "	20	20 "	20	11	5	5 "	17	17	17	14
O2OCT03	20	20	17	17	17	17 "	20	20 "	20	20	20	20 "	20	20 "	17	20	17	20 "	8	8	2	17
03OCT99	20	20	20	17	17	17 "	20	20 "	20	20	20	20 "	17	17 "	5	17	17	17 "	17	17	17	17
03OCT00	20	17	17	20	17	17 "	20	20 "	20	20	17	17 "	20	17 "	17	17	17	17 "	17	17	17	11
03OCT01	14	17	17	17	5	17 "	20	20 "	20	20	20	20 "	20	20 "	17	14	17	17 "	17	17	5	20
03OCT02	17	17	17	17	17	17 "	17	17 "	17	20	17	17 "	17	17 "	17	14	5	17 "	17	17	17	17
03OCT03	20	20	17	17	17	17 "	20	20 "	20	20	20	20 "	20	20 "	17	8	17	8 "	8	8	-1	17
04OCT99	17	14	17	17	17	17 "	20	20 "	17	20	17	20 "	20	17 "	17	17	17	17 "	17	17	17	17
04OCT00	20	17	17	17	17	17 "	17	17 "	20	20	20	17 "	17	17 "	5	17	17	17 "	17	17	17	17
04OCT01	14	17	17	17	17	17 "	20	20 "	20	20	20	17 "	17	14 "	14	17	17	17 "	14	14	17	17
04OCT02	17	17	17	17	17	17 "	17	17 "	17	17	17	17 "	17	17 "	17	17	17	5 "	17	17	17	17
04OCT03	20	17	17	17	17	17 "	17	20 "	20	20	20	20 "	20	17 "	17	5	8	17 "	17	8	8	-1
05OCT00	14	17	17	17	17	17 "	17	17 "	17	20	20	17 "	17	17 "	5	17	17	17 "	17	17	17	17
05OCT01	17	14	17	5	17	17 "	20	20 "	20	20	20	20 "	17	14 "	17	17	17	17 "	17	17	17	17

ICE NUMERALS-Canadian Arctic Ice Regime Shipping System(AIRSS)

Source : (Calculated from Canadian Ice services regional ice charts online Archives)

Ship type: **CAC3**

Region: **WEST ARCTIC**

Dates	Beaufort Sea						Amund Gulf		Coastal Straits				Queen Maud		Victoria Strait				Peel Sound			
01NOV99	20	17	17	17	17	17"	17	17"	17	17	17	17"	17	17"	8	8	17	17"	17	17	17	17
01NOV00	17	17	17	17	17	17"	17	17"	20	20	20	17"	17	17"	17	17	17	17"	17	17	17	17
01NOV01	14	17	5	17	17	20"	20	20"	20	20	20	20"	17	14"	17	17	17	14"	17	14	17	17
01NOV02	20	17	17	17	17	17"	17	17"	17	17	20	17"	17	17"	17	17	14	17"	17	17	17	17
01NOV03	20	17	17	17	17	17"	17	20"	20	20	20	17"	17	17"	5	8	17	17"	8	17	8	-1
02NOV99	17	17	17	17	8	17"	17	17"	17	17	17	17"	17	8"	8	8	17	17"	17	17	17	17
02NOV00	17	17	17	17	17	17"	17	17"	17	20	20	20"	17	17"	17	17	17	17"	17	17	17	17
02NOV01	17	14	17	8	17	17"	17	17"	17	17	17	17"	17	17"	17	17	17	17"	17	17	11	17
02NOV02	17	17	17	17	17	17"	17	17"	20	17	17	17"	17	17"	5	11	5	17"	11	17	17	17
02NOV03	20	20	17	17	17	17"	17	17"	17	20	20	17"	17	17"	5	17	17	17"	8	8	17	-1
03NOV99	17	17	17	17	17	14"	17	17"	17	17	14	17"	17	8"	8	8	17	17"	17	17	17	17
03NOV00	17	17	17	17	17	17"	17	17"	20	20	20	17"	17	17"	17	17	17	17"	17	17	17	17
03NOV01	17	14	8	17	17	17"	17	17"	17	17	17	17"	17	17"	17	17	17	17"	17	17	17	11
03NOV02	17	17	17	17	17	17"	14	17"	17	17	17	17"	17	17"	17	17	5	14"	14	17	17	17
03NOV03	17	17	17	17	17	17"	17	17"	17	20	20	20"	17	20"	17	-1	17	11"	11	17	11	-1
04NOV99	17	17	17	17	17	17"	17	17"	17	20	20	17"	17	8"	8	8	17	17"	17	17	17	17
04NOV00	17	17	17	17	17	17"	17	17"	17	20	20	17"	17	17"	17	17	17	17"	17	17	17	17
04NOV01	14	17	8	17	17	17"	17	17"	17	17	17	17"	14	17"	17	17	17	17"	17	17	11	17
04NOV02	17	17	17	17	17	17"	17	17"	17	20	17	17"	17	17"	5	5	17	17"	5	17	17	17
04NOV03	17	17	17	17	17	17"	17	17"	17	17	17	20"	17	17"	17	17	-1	17"	11	11	17	-1
05NOV00																						
05NOV01																						

ICE NUMERALS-Canadian Arctic Ice Regime Shipping System(AIRSS)

Source : (Calculated from Canadian Ice services regional ice charts online Archives)

Ship type: CAC3

Region: EAST ARCTIC

Dates	Lancaster Sound					Baffin Bay						Davis Strait					
01JAN99	17	17	8	8	8 "	8	11	17	17	17	17 "	20	20	17	17	17	17
01JAN00	17	17	17	17	17 "	17	17	17	17	20	20 "	17	17	20	20	17	17
01JAN01	17	17	17	11	17 "	14	17	17	20	20	17 "	20	20	17	17	17	17
01JAN02	17	17	17	17	17 "	5	14	17	17	17	17 "	20	17	17	17	17	17
01JAN03	17	17	17	17	17 "	17	17	17	17	20	17 "	20	20	20	17	17	17
01FEB99	20	20	20	17	20 "	17	17	17	17	17	20 "	20	17	20	20	17	17
01FEB00	17	17	17	17	17 "	17	17	17	17	20	20 "	20	20	20	17	17	17
01FEB01	17	17	17	14	17 "	14	17	8	17	17	17 "	20	20	20	20	17	17
01FEB02	17	17	17	17	17 "	17	17	17	17	17	17 "	20	20	17	17	17	17
01FEB03	17	17	17	17	17 "	17	17	17	20	17	17 "	17	17	17	17	17	17
01MAR99	20	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
01MAR00	17	17	17	17	17 "	17	17	17	17	17	17 "	20	20	20	17	17	17
01MAR01	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	20	20	17
01MAR02	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
01MAR03	17	17	17	17	17 "	14	14	17	17	20	20 "	20	20	17	17	20	17
01APR99	17	17	17	17	17 "	17	17	17	17	17	17 "	17	20	17	17	17	17
01APR00	17	17	17	17	17 "	17	17	17	17	17	20 "	17	17	17	17	17	17
01APR01	17	17	17	17	17 "	11	17	17	17	17	17 "	11	17	17	17	17	17
01APR02	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
01APR03	17	17	17	17	17 "	17	17	17	20	17	20 "	17	17	17	17	20	17
01DEC99	17	17	17	17	17 "	14	17	17	17	17	20 "	20	17	20	17	17	17
01DEC00	17	17	17	11	14 "	17	17	17	8	17	17 "	20	20	20	17	17	17
01DEC01	"	"	"	"	" "	"	"	"	"	"	" "	"	"	"	"	"	"
01DEC02	17	17	14	14	14 "	8	14	17	17	20	20 "	20	20	17	17	17	17
01DEC03	2	11	17	17	17 "	8	17	20	20	17	17 "	17	17	17	17	17	17

ICE NUMERALS-Canadian Arctic Ice Regime Shipping System(AIRSS)

Source : (Calculated from Canadian Ice services regional ice charts online Archives)
Ship type: **CAC3**
Region: **EAST ARCTIC**

Dates	Lancaster Sound						Baffin Bay						Davis Strait					
01MAY99	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
01MAY00	17	17	17	17	17	17 "	17	17	17	17	17	20 "	17	20	17	17	17	17
01MAY01	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	20	17	17
01MAY02	17	17	17	20	17	17 "	17	17	17	17	17	20 "	17	17	17	17	17	17
01MAY03	17	17	17	17	17	17 "	17	17	17	20	20	20 "	17	20	20	17	17	17
02MAY99	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02MAY00	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02MAY01	17	17	17	17	17	20 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02MAY02	17	17	17	17	17	17 "	17	17	17	17	20	20 "	17	17	17	17	17	17
02MAY03	17	17	17	17	17	17 "	17	17	17	17	20	20 "	17	20	17	17	17	17

ICE NUMERALS-Canadian Arctic Ice Regime Shipping System(AIRSS)

Source : (Calculated from Canadian Ice services regional ice charts online Archives)

Ship type: **CAC3**

Region: **EAST ARCTIC**

Dates	Lancaster Sound						Baffin Bay						Davis Strait					
01JUN99	20	17	17	17	20	20 "	17	17	17	14	17	17 "	17	17	17	17	17	17
01JUN00	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
01JUN01	17	17	17	17	17	17 "	17	17	17	17	17	17 "	14	17	17	17	17	17
01JUN02	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
01JUN03	17	17	17	17	17	17 "	17	17	20	14	17	17 "	14	14	17	17	17	17
02JUN99	20	17	17	17	17	20 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02JUN00	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02JUN01	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02JUN02	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02JUN03	17	17	17	17	17	17 "	17	17	17	17	17	14 "	14	14	17	17	17	14
03JUN99	20	17	17	17	20	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
03JUN00	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
03JUN01																		
03JUN02	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
03JUN03	17	17	17	17	17	17 "	17	17	17	17	14	17 "	14	17	14	17	17	17
04JUN99	20	17	17	17	20	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04JUN00	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04JUN01	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04JUN02	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04JUN03	17	17	17	17	17	17 "	17	17	17	17	17	17 "	14	17	17	14	17	17

ICE NUMERALS-Canadian Arctic Ice Regime Shipping System(AIRSS)

Source : (Calculated from Canadian Ice services regional ice charts online Archives)
Ship type: CAC3
Region: EAST ARCTIC

Dates	Lancaster Sound						Baffin Bay						Davis Strait					
01JUL99	20	17	17	20	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
01JUL00	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
01JUL01	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
01JUL02	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
01JUL03	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	14	17	17	17	17
02JUL99	20	17	17	17	20	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02JUL00	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02JUL01	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02JUL02	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02JUL03	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
03JUL99	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
03JUL00	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
03JUL01	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
03JUL02	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
03JUL03	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04JUL99	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04JUL00	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04JUL01	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04JUL02	17	17	17	14	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04JUL03	17	17	17	17	17	17 "	17	17	17	17	17	17 "	14	17	17	17	17	17
05JUL00	17	17	17	17	17	20 "	20	20	17	17	17	17 "	17	17	17	17	17	17
05JUL01	17	17	17	17	17	17 "	20	17	17	17	17	17 "	17	17	17	17	17	17

ICE NUMERALS-Canadian Arctic Ice Regime Shipping System(AIRSS)

Source : (Calculated from Canadian Ice services regional ice charts online Archives)

Ship type: **CAC3**

Region: **EAST ARCTIC**

Dates	Lancaster Sound						Baffin Bay						Davis Strait					
01AUG99	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
01AUG00	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
01AUG01	20	17	17	17	14	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
01AUG02	14	17	17	17	17	17 "	14	17	17	17	17	17 "	17	14	17	17	17	17
01AUG03	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02AUG99	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02AUG00	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02AUG01	14	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02AUG02	17	14	14	14	17	17 "	17	17	14	17	17	17 "	17	17	17	17	17	17
02AUG03	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
03AUG99	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
03AUG00	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
03AUG01	17	17	14	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
03AUG02	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
03AUG03	8	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04AUG99	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04AUG00	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04AUG01	14	14	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04AUG02	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04AUG03	8	17	8	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
05AUG99	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17

ICE NUMERALS-Canadian Arctic Ice Regime Shipping System(AIRSS)

Source : (Calculated from Canadian Ice services regional ice charts online Archives)
Ship type: CAC3
Region: EAST ARCTIC

Dates	Lancaster Sound						Baffin Bay						Davis Strait					
01SEP99	14	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
01SEP00	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
01SEP01	17	14	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
01SEP02	17	14	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
01SEP03	8	8	11	17	14	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02SEP99	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02SEP00	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02SEP01	14	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02SEP02	14	8	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02SEP03	11	17	11	8	5	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
03SEP99	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
03SEP00	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
03SEP01	17	14	11	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17 "	
03SEP02	11	8	17	14	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
03SEP03	2	17	14	17	2	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04SEP99	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04SEP00	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04SEP01	17	17	17	11	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04SEP02	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04SEP03	17	14	17	-4	11	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
05SEP02	14	14	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
05SEP03	14	-1	8	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17

ICE NUMERALS-Canadian Arctic Ice Regime Shipping System(AIRSS)

Source : (Calculated from Canadian Ice services regional ice charts online Archives)
Ship type: CAC3
Region: EAST ARCTIC

Dates	Lancaster Sound						Baffin Bay						Davis Strait					
01OCT99	17	17	14	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
01OCT00	17	-4	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
01OCT01	14	5	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
01OCT02	14	17	5	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
01OCT03	-1	2	17	11	17	-4 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02OCT99	14	17	17	17	14	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02OCT00	17	11	17	20	20	17 "	17	14	14	17	17	17 "	17	17	17	17	17	17
02OCT01	17	17	17	14	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02OCT02	14	17	14	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02OCT03	2	8	11	8	17	14 "	17	17	17	17	17	17 "	17	17	17	17	17	17
03OCT99	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
03OCT00	17	17	17	14	11	17 "	20	14	17	17	17	17 "	17	17	17	17	17	17
03OCT01	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
03OCT02	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
03OCT03	-1	17	-1	11	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04OCT99	17	17	17	14	17	17 "	17	17	20	17	17	17 "	17	17	17	17	17	17
04OCT00	17	17	5	17	2	17 "	14	17	17	20	17	17 "	17	17	17	17	17	17
04OCT01	17	17	17	17	11	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04OCT02	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
04OCT03	2	17	17	2	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
05OCT00	17	8	17	14	14	14 "	17	8	2	17	17	14 "	17	17	17	17	17	17
05OCT01	17	17	17	2	2	17 "	17	11	17	2	17	17 "	17	17	17	17	17	17

ICE NUMERALS-Canadian Arctic Ice Regime Shipping System(AIRSS)

Source : (Calculated from Canadian Ice services regional ice charts online Archives)
Ship type: CAC3
Region: EAST ARCTIC

Dates	Lancaster Sound						Baffin Bay						Davis Strait					
01NOV99	17	17	11	11	17	11 "	11	17	17	17	17	17 "	17	17	17	17	17	17
01NOV00	17	8	17	14	17	17 "	14	17	17	17	17	17 "	17	17	17	17	17	17
01NOV01	17	17	17	8	-4	2 "	17	5	17	20	17	17 "	17	17	17	17	17	17
01NOV02	17	17	17	17	14	17 "	14	17	17	20	17	17 "	17	17	17	17	17	17
01NOV03	-4	-1	17	17	17	17 "	17	17	17	17	17	17 "	17	17	17	17	17	17
02NOV99	17	17	17	14	14	17 "	14	17	17	17	17	17 "	17	17	17	17	17	17
02NOV00	17	17	17	14	8	14 "	14	17	17	17	17	17 "	17	17	17	17	17	17
02NOV01	17	17	17	11	17	2 "	2	17	17	17	17	17 "	17	17	17	17	17	17
02NOV02	17	17	14	14	17	17 "	17	14	14	17	17	17 "	17	17	17	17	17	17
02NOV03	-1	-1	17	17	17	17 "	17	17	20	17	17	17 "	20	17	17	17	17	17
03NOV99	17	17	17	14	17	17 "	14	17	17	17	20	17 "	20	20	17	17	17	17
03NOV00	17	8	17	14	8	17 "	17	8	17	17	17	17 "	20	17	17	17	17	17
03NOV01	17	17	17	11	17	17 "	2	17	17	17	17	20 "	20	17	17	17	17	17
03NOV02	17	17	17	17	14	17 "	17	17	17	17	14	17 "	17	17	17	17	17	17
03NOV03	-1	-4	17	17	17	17 "	17	17	20	20	17	17 "	20	17	17	17	17	17
04NOV99	17	17	17	17	17	17 "	17	17	17	17	17	17 "	17	14	20	17	17	17
04NOV00	17	8	17	14	17	17 "	11	8	17	17	17	17 "	20	20	17	17	17	17
04NOV01	17	17	17	14	17	17 "	14	17	17	17	20	17 "	20	20	20	17	17	17
04NOV02	17	17	17	14	17	17 "	14	17	17	17	17	17 "	20	20	20	17	17	17
04NOV03	-1	17	17	8	17	-1 "	17	17	17	20	20	17 "	20	17	17	17	17	17

Appendix 8 (Fitted Distributions for ice Numerals)

Week	Beafort Sea							Amundsen Gulf						
	Distribution	Parameters				Fit Criteria	VSLAM Variable	Distribution	Parameters				Fit Criteria	VSLAM Variable
		A	B	C	D				A	B	C	D		
01-Jan	Normal	16.1	3.5365			A-D/K-S	XX[1]	Constant	17				VISUAL	
01-Feb	Beta	5.0119	1.088	-4.6	20	A-D/K-S	XX[61]	Constant	17				VISUAL	
01-Mar	Normal	16.3	2.693			A-D/K-S	XX[2]	Constant	17				VISUAL	
01-Apr	Beta	4.7701	1.0007	-9.4	20	CHI/A-D/K-S	XX[62]	Normal	17.2	2.4495			P-P/Q-Q	XX[13]
01-May	Beta	10.757	1.1415	-26.84	20	CHI	XX[63]	Exponential	17.54				VISUAL	XX[133]
02-May	Beta	11.071	1.1693	-25.973	20	A-D/K-S	XX[64]	Exponential	17.54				VISUAL	XX[133]
01-Jun	Normal	16.8	2.7216			A-D/K-S	XX[3]	Exponential	17.54				VISUAL	XX[133]
02-Jun	Normal	16.3	4.5724			A-D/K-S	XX[4]	Exponential	17.54				VISUAL	XX[133]
03-Jun	Normal	16.8	2.3547			A-D/K-S	XX[5]	Exponential	18.08				VISUAL	XX[134]
04-Jun	Normal	16.875	2.3548			A-D/K-S	XX[6]	Beta	0.10389	0.10389	17	20	VISUAL	XX[70]
01-Jul	Triangular	8	17	20		VISUAL	XX[116]	Constant	20				VISUAL	
02-Jul	Normal	16.9	2.43			A-D/K-S	XX[7]	Constant	20				VISUAL	
03-Jul	Normal	17.3	2.28			A-D/K-S	XX[8]	Constant	20				VISUAL	
04-Jul	Normal	16.36	2.6116			A-D/K-S	XX[9]	Normal	18.5	1.9513			VISUAL	XX[14]
01-Aug	Normal	16.7	3.0867			A-D	XX[10]	Constant	20				VISUAL	
02-Aug	Normal	16.1	3.872			A-D/K-S	XX[11]	Constant	20				VISUAL	
03-Aug	Normal	14.2	7.6762			A-D/K-S	XX[12]	Constant	20				VISUAL	
04-Aug	Beta	0.56733	0.1406	2	20	A-D/K-S	XX[65]	Constant	20				VISUAL	
01-Sep	Triangular	14	20	20		VISUAL	XX[117]	Normal	19.1	2.846			CHI/A-D/K-S	XX[15]
02-Sep	Triangular	11	20	20		VISUAL	XX[118]	Constant	20				VISUAL	
03-Sep	Triangular	-1	20	20		CHI/VISUAL	XX[119]	Constant	20				VISUAL	
04-Sep	Beta	0.61325	0.10442	-1	20	VISUAL	XX[66]	Constant	20				VISUAL	
01-Oct	Exponential	18.1567				CHI/KS	XX[132]	Constant	20				VISUAL	
02-Oct	Beta	0.5864	0.17834	2	20	CHI/A-D	XX[67]	Constant	20				VISUAL	
03-Oct	Beta	1.5533	0.30276	4	20	CHI/K-S	XX[68]	Constant	20				VISUAL	
04-Oct	Beta	52.977	4.8306	-29.25654	20.765		XX[69]	Beta	0.10389	0.10389	17	20	CHI	XX[70]
01-Nov	Triangular	5	17	20		VISUAL	XX[120]	Beta	0.88959	0.13676	17	20	CHI/VISUAL	XX[71]
02-Nov	Triangular	8	17	20		CHI/VISUAL	XX[116]	Constant	17				VISUAL	
03-Nov	Triangular	8	17	17		CHI/VISUAL	XX[121]	Constant	17				VISUAL	
04-Nov	Triangular	8	17	17		CHI/VISUAL	XX[121]	Constant	17				VISUAL	
01-Dec	Constant	17				VISUAL		Constant	17				VISUAL	

Week	Coastal Straits							Queen Maud						
	Distribution	Parameters				Fit Criteria	VSLAM Variable	Distribution	Parameters				Fit Criteria	VSLAM Variable
		A	B	C	D				A	B	C	D		
01-Jan	Beta	0.09507	0.11676	17	20	CHI	XX[72]	Constant	17				VISUAL	
01-Feb	Beta	0.099082	0.10969	17	20	CHI	XX[73]	Normal	15.5	3.2404			VISUAL	XX[22]
01-Mar	Beta	0.099082	0.10969	17	20	CHI	XX[73]	Normal	15.8	3.5214			VISUAL	XX[23]
01-Apr	Normal	18.8	1.5213			A-D/K-S	XX[16]	Triangular	8	17	17		VISUAL	XX[121]
01-May	Normal	18.2	1.5079			A-D/K-S	XX[17]	Normal	15.5	3.2404			P-P/Q-Q	XX[22]
02-May	Normal	18.2	1.5079			A-D/K-S	XX[17]	Normal	15.8	3.5214			CHI/A-D	XX[23]
01-Jun	Constant	20				CHI		Normal	16.4	1.8974			A-D/K-S	XX[24]
02-Jun	Beta	0.10389	0.10389	17	20	VISUAL	XX[70]	Exponetial	16.13				P-P/Q-Q	XX[136]
03-Jun	Beta	0.91726	0.12555	17	20	VISUAL	XX[74]	Exponetial	16.13				P-P/Q-Q	XX[136]
04-Jun	Beta	0.0869	0.133689	17	20	VISUAL	XX[75]	Exponetial	15.92				P-P/Q-Q	XX[137]
01-Jul	Normal	18.35	1.8144			VISUAL	XX[18]	Normal	15.8	3.5214			CHI/A-D/K-S	XX[23]
02-Jul	Exponential	17.7				P-P/Q-Q/CHI	XX[135]	Triangular	11	17	20		VISUAL	XX[123]
03-Jul	Beta	0.10389	0.10389	17	20	VISUAL	XX[70]	Triangular	11	17	20		VISUAL	XX[123]
04-Jul	Beta	0.11254	0.099274	17	20	VISUAL	XX[76]	Exponential	16.78	1.449			CHI/A-D/K-S	XX[138]
01-Aug	Normal	19.55	1.4681			A-D/K-S	XX[19]	Beta	0.13676	0.088959	14	20	VISUAL	XX[81]
02-Aug	Constant	20				VISUAL		Constant	20				VISUAL	
03-Aug	Constant	20				VISUAL		Constant	20				VISUAL	
04-Aug	Constant	20				VISUAL		Constant	20				VISUAL	
01-Sep	Normal	19.7	0.924			A-D/K-S/P-P	XX[20]	Constant	20				VISUAL	
02-Sep	Constant	20				VISUAL		Constant	20				VISUAL	
03-Sep	Constant	20				VISUAL		Beta	0.25817	0.083508	17	20	VISUAL	XX[82]
04-Sep	Constant	20				VISUAL		Constant	20				VISUAL	
01-Oct	Constant	20				VISUAL		Constant	20				VISUAL	
02-Oct	Constant	20				VISUAL		Beta	0.26382	0.091639	11	20	VISUAL	XX[83]
03-Oct	Beta	0.15157	0.086725	17	20	VISUAL	XX[77]	Beta	0.10389	0.10389			VISUAL	XX[70]
04-Oct	Beta	0.12417	0.092166	17	20	VISUAL	XX[78]	Triangular	14	17	20		K-S	XX[122]
01-Nov	Beta	0.10969	0.092166	17	20	VISUAL	XX[79]	Constant	17				VISUAL	
02-Nov	Beta	0.088959	0.13676	17	20	VISUAL	XX[80]	Constant	17				VISUAL	
03-Nov	Triangular	14	17	20		VISUAL	XX[122]	Exponential	15.56				CHI/P-P	XX[139]
04-Nov	Beta	0.88959	0.13676	17	20	VISUAL	XX[80]	Normal	15.8	2.8983			CHI/A-D/K-S	XX[25]
01-Dec	Normal	17.75	1.7321			VISUAL	XX[21]	Beta	0.22634	0.083582	17	20	VISUAL	XX[84]

Week	Victoria Strait							Peel Sound						
	Distribution	Parameters				Fit Criteria	VSLAM Variable	Distribution	Parameters				Fit Criteria	VSLAM Variable
		A	B	C	D				A	B	C	D		
01-Jan	Normal	14.5	4.594				XX[26]	Normal	17	1.685			A-D/Q-Q	XX[33]
01-Feb	Normal	14.5	4.594				XX[26]	Normal	16.1	3.7822			A-D/K-S/CHI	XX[34]
01-Mar	Normal	14.5	4.594				XX[26]	Normal	16.1	3.6545			A-D	XX[35]
01-Apr	Exponential	12.8375				CHI/K-S	XX[140]	Normal	14.9	4.14			A-D	XX[36]
01-May	Normal	14.9	4.3637			P-P	XX[27]	Normal	16.1	3.6548			A-D/K-S	XX[35]
02-May	Normal	14.5	4.594			P-P	XX[26]	Normal	16.1	3.6548			A-D/K-S	XX[35]
01-Jun	Triangular	5	17	17		VISUAL	XX[124]	Triangular	11	17	17		VISUAL/P-P	XX[125]
02-Jun	Triangular	5	17	17		VISUAL	XX[124]	Triangular	11	17	17		VISUAL/P-P	XX[125]
03-Jun	Exponential	13.4075				CHI/P-P	XX[141]	Exponential	16.2725				P-P/CHI	XX[144]
04-Jun	Exponential	12.5586				CHI/P-P	XX[142]	Normal	15.31	4.0942			VISUAL	XX[37]
01-Jul	Beta	0.36308	0.26424	5	20	CHI/VISUAL	XX[85]	Normal	17	2.3842			A-D/VISUAL	XX[38]
02-Jul	Exponential	13.55				CHI/P-P	XX[143]	Triangular	2	17	17		VISUAL/CHI	XX[126]
03-Jul	Beta	0.32581	0.37724	5	20	CHI/KS	XX[86]	Normal	16.25	2.359			VISUAL/K-S	XX[39]
04-Jul	Triangular	5	17	20		VISUAL	XX[120]	Triangular	5	17	20		VISUAL/CHI	XX[120]
01-Aug	Beta	1.9041	0.75627	3.136	20	VISUAL/K-S	XX[87]	Triangular	14	17	20		VISUAL/K-S	XX[122]
02-Aug	Beta	18.136	10.82	5.29	23.46	A-D/K-S	XX[88]	Normal	18.05	1.7614			A-D/CHI	XX[40]
03-Aug	Normal	16.85	2.2775			A-D/K-S	XX[28]	Normal	17.15	3.297			A-D/K-S/P-P	XX[41]
04-Aug	Normal	16.875	2.4194			A-D/K-S	XX[29]	Normal	17.625	3.5363			A-D/K-S/P-P	XX[42]
01-Sep	Beta	0.43281	0.13945	5	20	VISUAL	XX[89]	Normal	17.45	3.2683			A-D/K-S/P-P	XX[43]
02-Sep	Beta	0.4376	0.13892	5	20	VISUAL	XX[90]	Normal	17.9	2.594			A-D/K-S/P-P	XX[44]
03-Sep	Normal	17.45	4.0455			A-D/K-S	XX[30]	Normal	17.15	4.614			A-D/K-S/CHI	XX[45]
04-Sep	Beta	0.33586	0.10687	2	20	VISUAL	XX[91]	Normal	16.357	6.2906			A-D/K-S/CHI	XX[46]
01-Oct	Beta	0.3364	0.20929	11	20	VISUAL	XX[92]	Normal	15.2	5.2776			A-D/CHI	XX[47]
02-Oct	Normal	15.35	4.7159			CHI/A-D	XX[31]	Beta	0.37892	0.10385	2	17	VISUAL	XX[99]
03-Oct	Beta	0.26092	0.10222	5	17	VISUAL	XX[93]	Normal	14.45	5.3555			A-D/CHI	XX[48]
04-Oct	Beta	0.21115	0.089757	5	17	VISUAL	XX[94]	Beta	0.47841	0.09816	-1	17	VISUAL	XX[100]
01-Nov	Beta	0.36189	0.10968	5	17	VISUAL	XX[95]	Triangular	-2	17	17		CHI	XX[127]
02-Nov	Beta	0.20509	0.098057	5	17	VISUAL/P-P	XX[96]	Triangular	-2	17	17		CHI	XX[127]
03-Nov	Beta	0.38692	0.1094	-1	17	CHI/P-P	XX[97]	Triangular	-2	17	17		CHI	XX[127]
04-Nov	Beta	0.36976	0.10423	-1	17	CHI/VISUAL	XX[98]	Triangular	-2	17	17		CHI	XX[127]
01-Dec	Normal	13.4375	5.9214			A-D/K-S	XX[32]	Normal	15.6875	3.9449			A-D/K-S	XX[49]

Week	Lancaster Sound							Baffin Bay						
	Distribution	Parameters				Fit Criteria	VSLAM Variable	Distribution	Parameters				Fit Criteria	VSLAM Variable
		A	B	C	D				A	B	C	D		
01-Jan	Beta	0.25757	0.086365			VISUAL	XX[101]	Triangular	5	17	20		VISUAL	XX[120]
01-Feb	Lognormal	17.3	1.1695			CHI/VISUAL	XX[60]	Beta	1.691	0.46312	7	20	VISUAL	XX[109]
01-Mar	Constant	17				VISUAL		Triangular	14	17	20		CHI/K-S	XX[122]
01-Apr	Constant	17				VISUAL		Normal	17.1	1.4704			A-D/K-S	XX[54]
01-May	Constant	17				VISUAL		Beta	0.0842	0.19135	17	20	CHI/VISUAL	XX[110]
02-May	Constant	17				VISUAL		Beta	0.0837	0.21794	17	20	CHI/VISUAL	XX[111]
01-Jun	Beta	0.083508	0.25817	17	20	CHI/VISUAL	XX[102]	Triangular	14	17	20		A-D/K-S/CHI	XX[122]
02-Jun	Beta	0.08392	0.28772	17	20	CHI/VISUAL	XX[103]	Constant	17				VISUAL	
03-Jun	Beta	0.083624	0.28772	17	20	CHI/VISUAL	XX[104]	Constant	17				VISUAL	
04-Jun	Constant	17				VISUAL		Constant	17				VISUAL	
01-Jul	Constant	17				VISUAL		Constant	17				VISUAL	
02-Jul	Constant	17				VISUAL		Constant	17				VISUAL	
03-Jul	Constant	17				VISUAL		Constant	17				VISUAL	
04-Jul	Constant	17				VISUAL		Constant	17				VISUAL	
01-Aug	Constant	17				VISUAL		Constant	17				VISUAL	
02-Aug	Beta	0.21794	0.08366	14	17	VISUAL	XX[105]	Constant	17				VISUAL	
03-Aug	Triangular	8	17	17		VISUAL/CHI	XX[121]	Constant	17				VISUAL	
04-Aug	Beta	0.36932	0.0887	8	17	VISUAL	XX[106]	Constant	17				VISUAL	
01-Sep	Normal	15.8	2.565			A-D/K-S	XX[50]	Constant	17				VISUAL	
02-Sep	Triangular	5	17	17			XX[124]	Constant	17				VISUAL	
03-Sep	Triangular	1	17	17		CHI	XX[128]	Constant	17				VISUAL	
04-Sep	Beta	0.58488	0.10462	-4	17	VISUAL/P-P	XX[107]	Constant	17				VISUAL	
01-Oct	Beta	0.32821	0.11005	-4	17	VISUAL	XX[108]	Constant	17				VISUAL	
02-Oct	Triangular	2	17	20		CH/IVISUAL	XX[129]	Constant	17				VISUAL	
03-Oct	Normal	15.3	4.7062			CHI/A-D/K-S	XX[51]	Constant	17				VISUAL	
04-Oct	Normal	14.2857	5.2092			A-D/K-S	XX[52]	Triangular	2	17	20		CHI/VISUAL	XX[129]
01-Nov	Normal	13.1	6.5986			A-D/K-S	XX[53]	Normal	16.4	2.66			A-D/K-S	XX[55]
02-Nov	Triangular	-1	17	17		CHI/VISUAL	XX[130]	Normal	16.2	2.9408			A-D/K-S	XX[56]
03-Nov	Triangular	-4	17	17		CHI/VISUAL	XX[131]	Normal	16.4	3.4701			A-D/K-S	XX[57]
04-Nov	Triangular	-2	17	17		CHI/VISUAL	XX[127]	Normal	16.6	2.3282			A-D/K-S	XX[58]
01-Dec	Triangular	2	17	17		CHI/P-P	XX[127]	Normal	16.25	3.5661			CHI/A-D	XX[59]

Week	Davis Strait						
	Distributio	arameters				Fit Criteria	VSLAM Variable
		A	B	C	D		
01-Jan	Beta	0.091	0.13	17	20	CHI/VISUAL	XX[112]
01-Feb	Beta	0.095	0.12	17	20	CHI/VISUAL	XX[72]
01-Mar	Beta	0.087	0.15	17	20	CHI/VISUAL	XX[114]
01-Apr	Beta	48.33	22	0.4	24.52	CHI/K-S	XX[115]
01-May	Beta	0.084	0.22	17	20	CHI/VISUAL	XX[111]
02-May	Constant	17				VISUAL	
01-Jun	Beta	0.258	0.08	17	20	VISUAL	XX[82]
02-Jun	Constant	17				VISUAL	
03-Jun	Constant	17				VISUAL	
04-Jun	Constant	17				VISUAL	
01-Jul	Constant	17				VISUAL	
02-Jul	Constant	17				VISUAL	
03-Jul	Constant	17				VISUAL	
04-Jul	Constant	17				VISUAL	
01-Aug	Constant	17				VISUAL	
02-Aug	Constant	17				VISUAL	
03-Aug	Constant	17				VISUAL	
04-Aug	Constant	17				VISUAL	
01-Sep	Constant	17				VISUAL	
02-Sep	Constant	17				VISUAL	
03-Sep	Constant	17				VISUAL	
04-Sep	Constant	17				VISUAL	
01-Oct	Constant	17				VISUAL	
02-Oct	Constant	17				VISUAL	
03-Oct	Constant	17				VISUAL	
04-Oct	Constant	17				VISUAL	
01-Nov	Constant	17				VISUAL	
02-Nov	Constant	17				VISUAL	
03-Nov	Constant	20				VISUAL	
04-Nov	Constant	20				VISUAL	
01-Dec	Beta	0.089	0.14	17	20	CHI/VISUAL	XX[113]

Key to Distribution types and Parameters

	A	B	C	D
Normal	Mean	Std Dev		
Lognorm	Mean	Std Dev		
Beta Ger	Theta	Phi	Min Valu	Max value
Traingula	Min	Mode	Max Value	
Exponen	Mean			

Legend for fit Criteria

CHI	Chi -Squared Statistics
A-D	Anderson - Darling Statistics
K-S	Kolmogorov - Smirnov Statistics
VISUAL	Based on visual evaluation of distribution superimposed on Histogram and optimum confidence intervals matching data
P-P/Q-Q	Probability-Probablity/Quantile-Quantile plots

Note:
VSLAM Global variable assigned to each distribution type is shown.

Appendix 9

VSLAM Network and Control Statements

for round trip transit simulation

Scenario – Yokohama to St John's through Arctic.

VSLAM/AWESLIM Control statement

```
GEN,"SARAN","CAPSTONE",11/7/2004,300,YES,YES;
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ARRAY,51,9,{1018,275,284,58,190,200,246,564,595};
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NETWORK,READ;
FIN;
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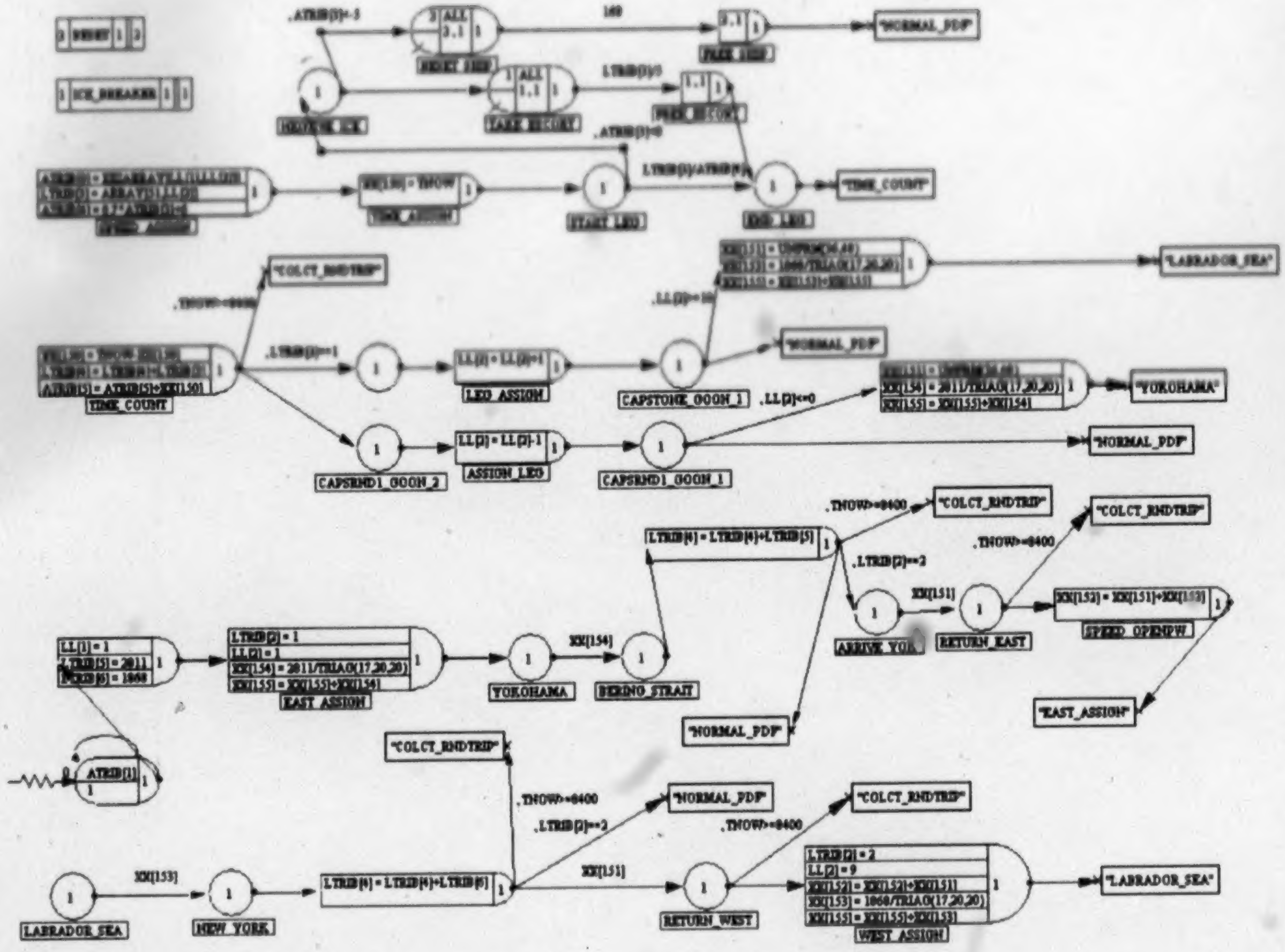
Appendix 9 (VSLAM Network Page 1 of 5)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ALL
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160
1,1
LTRIB(1)/ATRIB(8)
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END_LEG
"NORMAL_PDF"
"TIME_COUNT"
"LABRADOR_SEA"
"COLCT_RNDTRIP"
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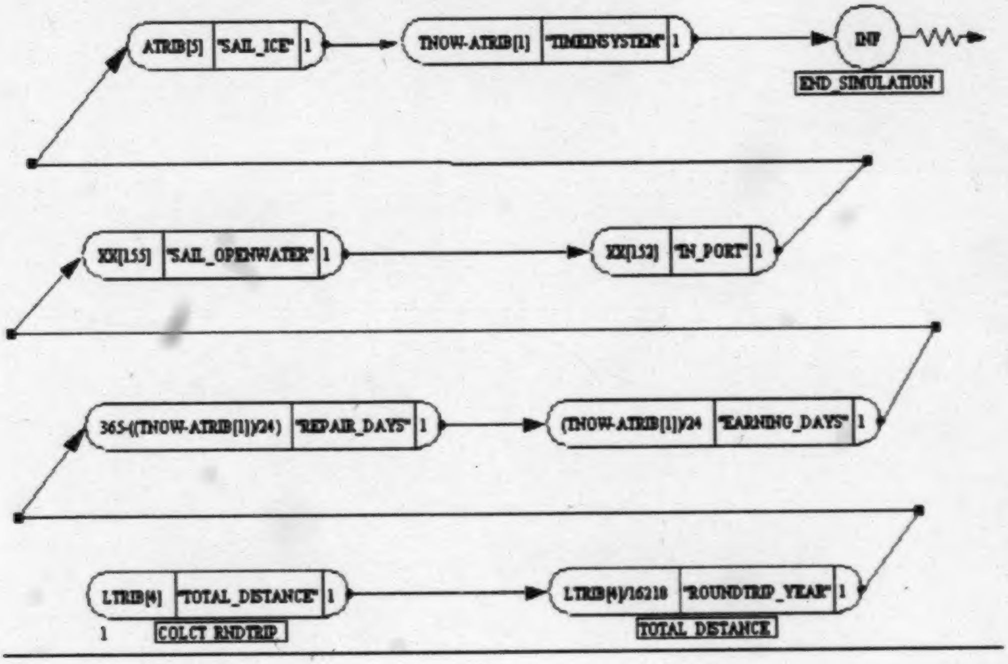
TIME_COUNT
LL[2] = LL[2]+1
LEG_ASSIGN
CAPSTONE_GOON_1
.LL[2]<=0
XX[154] = 2011/TRIAG(17,20,20)
XX[155] = XX[155]+XX[154]
"YOKOHAMA"
LL[2] = LL[2]-1
ASSIGN_LEG
CAPSRND1_GOON_2
CAPSRND1_GOON_1
.TNOW>=8400
LTRIB[4] = LTRIB[4]+LTRIB[5]
.LTRIB[2]==2
XX[151]
ARRIVE_YOK
RETURN_EAST
XX[152] = XX[151]+XX[153]
SPEED_OPENPW
"EAST_ASSIGN"
LL[1] = 1
LTRIB[5] = 2011
LTRIB[6] = 1868
LTRIB[2] = 1
LL[2] = 1
EAST_ASSIGN
YOKOHAMA
XX[154]
BERING_STRAIT
ATRIB[1]
LABRADOR_SEA
XX[153]
NEW_YORK
LTRIB[4] = LTRIB[4]+LTRIB[6]
RETURN_WEST
LTRIB[2] = 2
LL[2] = 9
XX[152] = XX[152]+XX[151]
XX[153] = 1868/TRIAG(17,20,20)
XX[155] = XX[155]+XX[153]
WEST_ASSIGN
"LABRADOR_SEA"

Appendix 9 (VSLAM Network Page 2 of 5)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"TIMEINSYSTEM"
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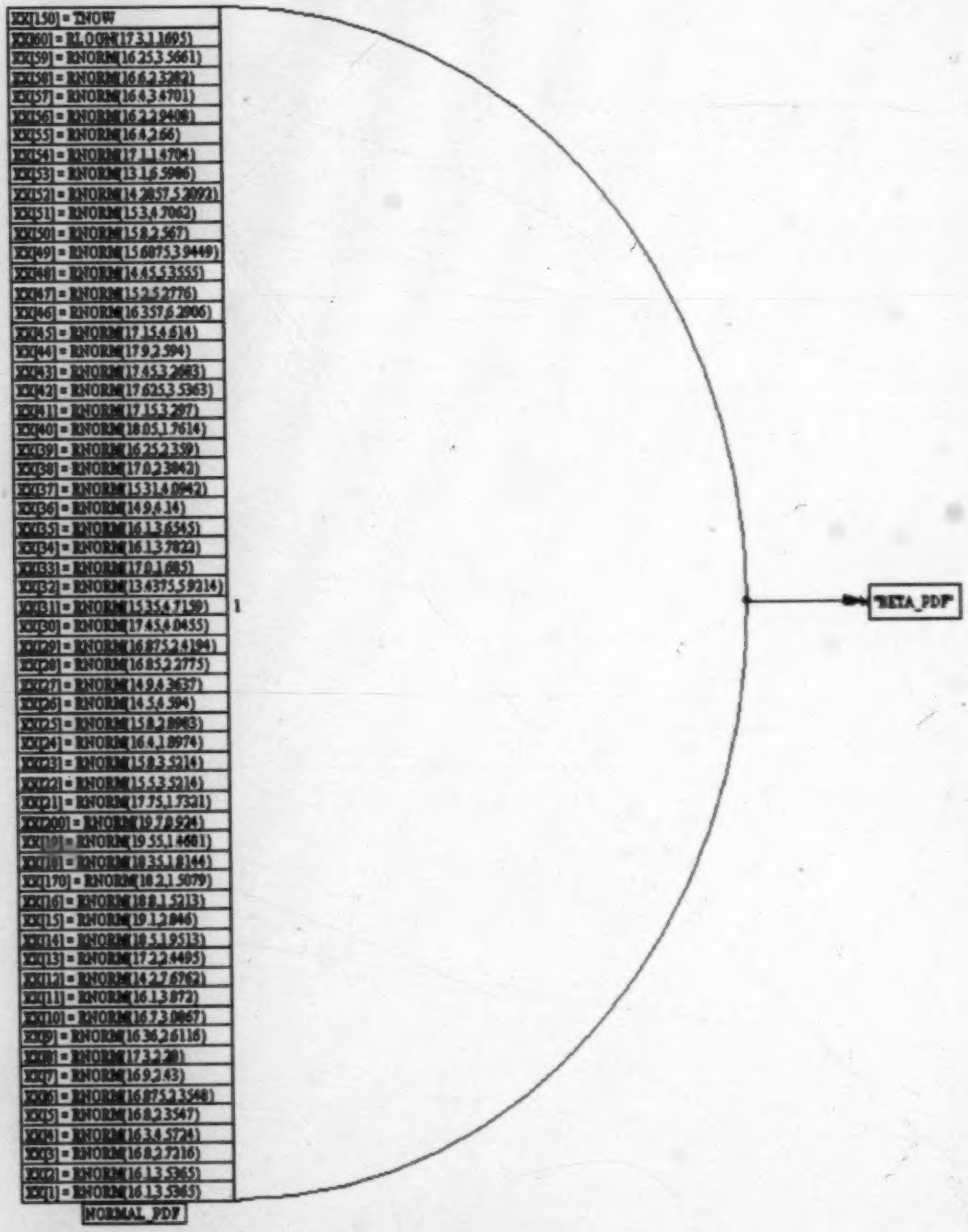
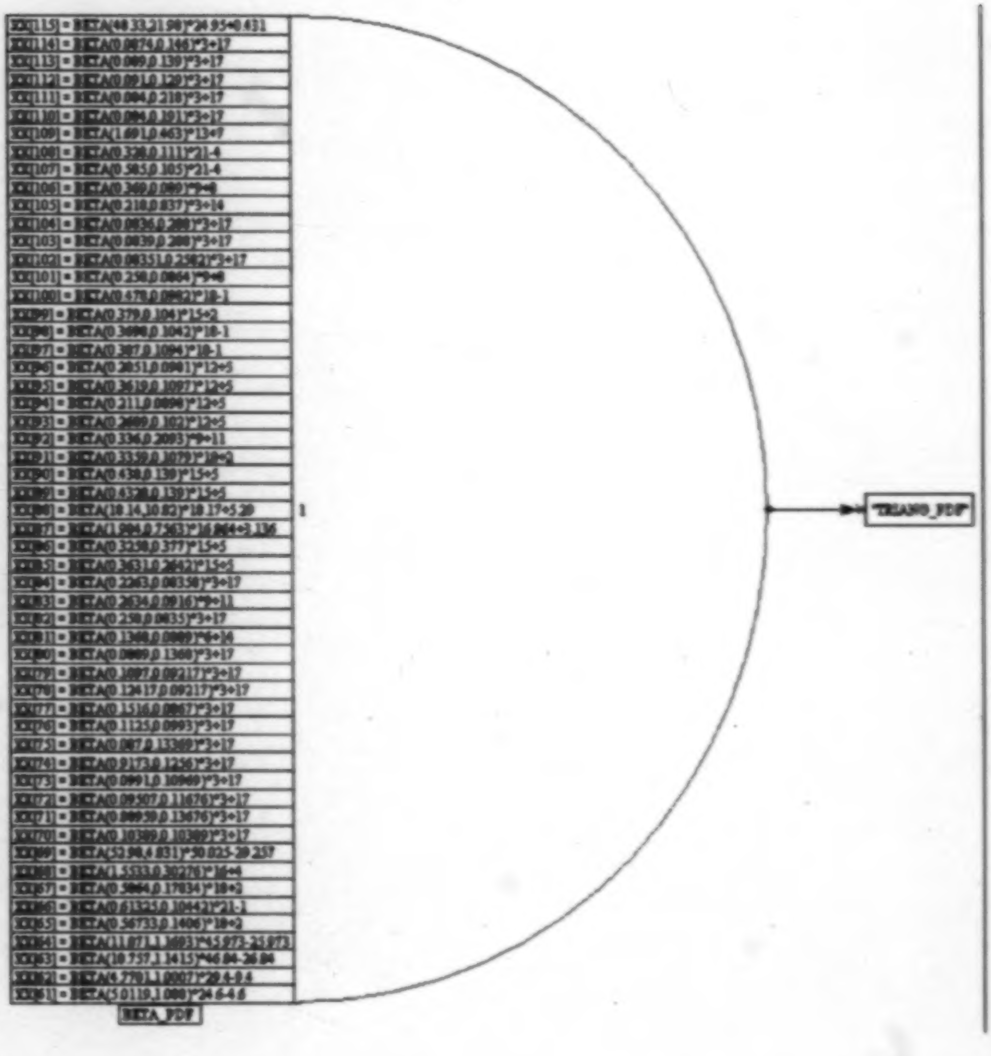
INF
END_SIMULATION
XX[155]
"SAIL_OPENWATER"
1
XX[152]
"IN_PORT"
1
365-((TNOW-ATRIB[1])/24)
"REPAIR_DAYS"
1
(TNOW-ATRIB[1])/24
"EARNING_DAYS"
1
LTRIB[4]
"TOTAL_DISTANCE"
1
1
COLCT RNDTRIP
LTRIB[4]/16218
"ROUNDTRIP_YEAR"
1
TOTAL DISTANCE

Appendix 9 (VSLAM Network Page 3 of 5)


XX[150] = TNOW
XX[60] = RLOGN(17.3,1.1695)
XX[59] = RNORM(16.25,3.5661)
XX[58] = RNORM(16.6,2.3282)
XX[57] = RNORM(16.4,3.4701)
XX[56] = RNORM(16.2,2.9408)
XX[55] = RNORM(16.4,2.66)
XX[54] = RNORM(17.1,1.4704)
XX[53] = RNORM(13.1,6.5986)
XX[52] = RNORM(14.2857,5.2092)
XX[51] = RNORM(15.3,4.7062)
XX[50] = RNORM(15.8,2.567)
XX[49] = RNORM(15.6875,3.9449)
XX[48] = RNORM(14.45,5.3555)
XX[47] = RNORM(15.2,5.2776)
XX[46] = RNORM(16.357,6.2906)
XX[45] = RNORM(17.15,4.614)
XX[44] = RNORM(17.9,2.594)
XX[43] = RNORM(17.45,3.2683)
XX[42] = RNORM(17.625,3.5363)
XX[41] = RNORM(17.15,3.297)
XX[40] = RNORM(18.05,1.7614)
XX[39] = RNORM(16.25,2.359)
XX[38] = RNORM(17.0,2.3042)
XX[37] = RNORM(15.31,4.0942)
XX[36] = RNORM(14.9,4.14)
XX[35] = RNORM(16.1,3.6545)
XX[34] = RNORM(16.1,3.7822)
XX[33] = RNORM(17.0,1.685)
XX[32] = RNORM(13.4375,5.9214)
XX[31] = RNORM(15.35,4.7159)
XX[30] = RNORM(17.45,4.0455)
XX[29] = RNORM(16.875,2.4194)
XX[28] = RNORM(16.85,2.2775)
XX[27] = RNORM(14.9,4.3637)
XX[26] = RNORM(14.5,4.594)
XX[25] = RNORM(15.8,2.8983)
XX[24] = RNORM(16.4,1.8974)
XX[23] = RNORM(15.8,3.5214)
XX[22] = RNORM(15.5,3.5214)
XX[21] = RNORM(17.75,1.7321)
XX[200] = RNORM(19.7,0.924)
XX[19] = RNORM(19.55,1.4601)
XX[18] = RNORM(18.35,1.8144)
XX[170] = RNORM(18.2,1.5079)
XX[16] = RNORM(18.8,1.5213)
XX[15] = RNORM(19.1,2.046)
XX[14] = RNORM(18.5,1.9513)
XX[13] = RNORM(17.2,2.4495)
XX[12] = RNORM(14.2,7.6762)
XX[11] = RNORM(16.1,3.872)
XX[10] = RNORM(16.7,3.0867)
XX[9] = RNORM(16.36,2.6116)
XX[8] = RNORM(17.3,2.28)
XX[7] = RNORM(16.9,2.43)
XX[6] = RNORM(16.875,2.3598)
XX[5] = RNORM(16.8,2.3547)
XX[4] = RNORM(16.3,4.5724)
XX[3] = RNORM(16.8,2.7216)
XX[2] = RNORM(16.1,3.5365)
XX[1] = RNORM(16.1,3.5365)
NORMAL_PDF
1
"BETA_PDF"

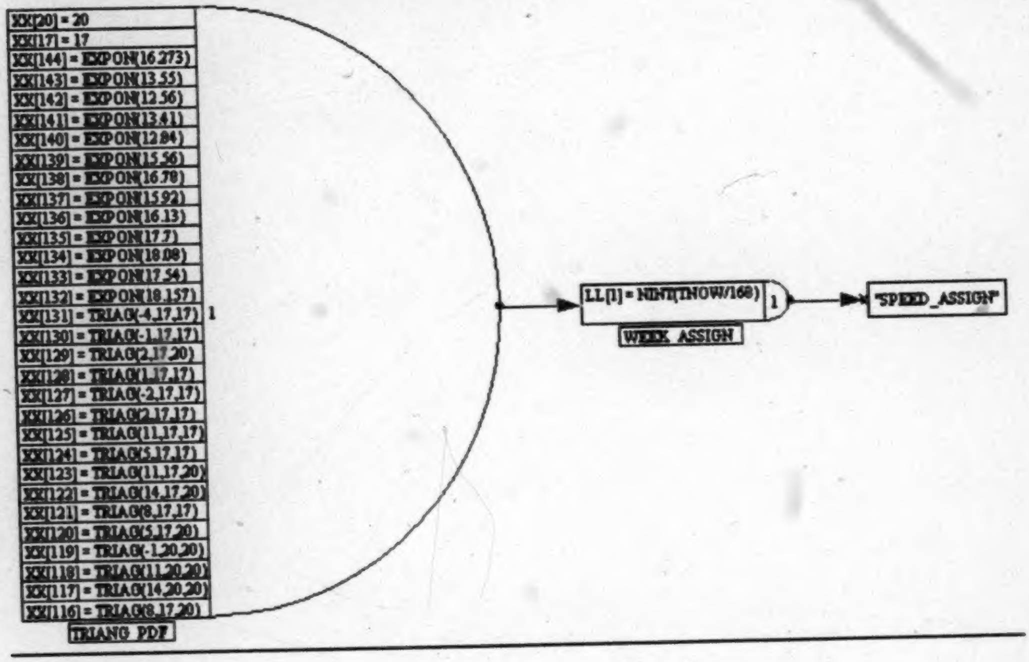
Normal Distribution used for ice numeral Inputs

Appendix 9 (VSLAM Network Page 4 of 5)


XX[115] = BETA(48.33,21.98)*24.95+0.431
XX[114] = BETA(0.0074,0.146)*3+17
XX[113] = BETA(0.009,0.139)*3+17
XX[112] = BETA(0.091,0.129)*3+17
XX[111] = BETA(0.004,0.218)*3+17
XX[110] = BETA(0.094,0.191)*3+17
XX[109] = BETA(1.691,0.463)*13+7
XX[108] = BETA(0.328,0.111)*21-4
XX[107] = BETA(0.585,0.105)*21-4
XX[106] = BETA(0.369,0.089)*9+8
XX[105] = BETA(0.218,0.837)*3+14
XX[104] = BETA(0.0836,0.280)*3+17
XX[103] = BETA(0.0839,0.280)*3+17
XX[102] = BETA(0.08351,0.2582)*3+17
XX[101] = BETA(0.258,0.0864)*9+8
XX[100] = BETA(0.478,0.0982)*18-1
XX[99] = BETA(0.379,0.104)*15+2
XX[98] = BETA(0.3698,0.1042)*18-1
XX[97] = BETA(0.307,0.1094)*18-1
XX[96] = BETA(0.2851,0.0981)*12+5
XX[95] = BETA(0.3619,0.1097)*12+5
XX[94] = BETA(0.211,0.0898)*12+5
XX[93] = BETA(0.2689,0.102)*12+5
XX[92] = BETA(0.336,0.2093)*9+11
XX[91] = BETA(0.3359,0.1079)*10+9
XX[90] = BETA(0.438,0.139)*15+5
XX[89] = BETA(0.4378,0.139)*15+5
XX[88] = BETA(18.14,10.82)*18.17+5.20
XX[87] = BETA(1.906,0.7563)*16.864+3.136
XX[86] = BETA(0.3258,0.377)*15+5
XX[85] = BETA(0.3631,0.2647)*15+5
XX[84] = BETA(0.2263,0.08358)*3+17
XX[83] = BETA(0.2634,0.0916)*9+11
XX[82] = BETA(0.258,0.0835)*3+17
XX[81] = BETA(0.1348,0.0889)*6+14
XX[80] = BETA(0.0889,0.1348)*3+17
XX[79] = BETA(0.1097,0.09217)*3+17
XX[78] = BETA(0.12417,0.09217)*3+17
XX[77] = BETA(0.1516,0.0867)*3+17
XX[76] = BETA(0.1125,0.0993)*3+17
XX[75] = BETA(0.087,0.13389)*3+17
XX[74] = BETA(0.9173,0.1256)*3+17
XX[73] = BETA(0.0991,0.10969)*3+17
XX[72] = BETA(0.09507,0.11676)*3+17
XX[71] = BETA(0.0950,0.13676)*3+17
XX[70] = BETA(0.10389,0.10389)*3+17
XX[69] = BETA(52.90,4.831)*50.025-29.257
XX[68] = BETA(1.5533,0.30271)*16+4
XX[67] = BETA(0.5064,0.17834)*18+2
XX[66] = BETA(0.61325,0.10442)*21-1
XX[65] = BETA(0.56733,0.1406)*18+2
XX[64] = BETA(11.071,1.3693)*45.973-25.973
XX[63] = BETA(10.757,1.1415)*46.04-26.04
XX[62] = BETA(4.770,1.0007)*29.4-9.4
XX[61] = BETA(5.0119,1.008)*24.6-4.6
BETA_PDF
1
"TRIANG_PDF"

Beta Distribution used for Ice Numeral inputs

Appendix 9 (VSLAM Network Page 5 of 5)


XX[20] = 20
XX[17] = 17
XX[144] = EXPON(16.273)
XX[143] = EXPON(13.55)
XX[142] = EXPON(12.56)
XX[141] = EXPON(13.41)
XX[140] = EXPON(12.84)
XX[139] = EXPON(15.56)
XX[138] = EXPON(16.78)
XX[137] = EXPON(15.92)
XX[136] = EXPON(16.13)
XX[135] = EXPON(17.7)
XX[134] = EXPON(18.08)
XX[133] = EXPON(17.54)
XX[132] = EXPON(18.157)
XX[131] = TRIAG(-4,17,17)
XX[130] = TRIAG(-1,17,17)
XX[129] = TRIAG(2,17,20)
XX[128] = TRIAG(1,17,17)
XX[127] = TRIAG(-2,17,17)
XX[126] = TRIAG(2,17,17)
XX[125] = TRIAG(11,17,17)
XX[124] = TRIAG(5,17,17)
XX[123] = TRIAG(11,17,20)
XX[122] = TRIAG(14,17,20)
XX[121] = TRIAG(8,17,17)
XX[120] = TRIAG(5,17,20)
XX[119] = TRIAG(-1,20,20)
XX[118] = TRIAG(11,20,20)
XX[117] = TRIAG(14,20,20)
XX[116] = TRIAG(8,17,20)
1
TRIANG PDF
LL[1] = NINT(TNOW/168)
1
WEEK ASSIGN
"SPEED_ASSIGN"

Triangular and Exponential distributions used for Ice Numeral inputs

Appendix 10

Transit simulation result round trip version

```
        ** AweSim! MULTIPLE RUN SUMMARY REPORT **
        Sat Aug 28 18:33:39 2004


  Simulation Project: CAPSTONE
  Modeller: SARAN
  Date: 11/7/2004
  Scenario: BASECASE YOK - St John's Fast Ship (Arctic)
  Number of runs 300


         ** OBSERVED STATISTICS for scenario BASECASE **

Label          Units    Mean       Standard      Minimum     Maximum
                        Value      Deviation     Average     Average
                                                 Value       Value

TOTAL_DISTANCE    NM    136650.893 1884.998     133304.000 140320.000
ROUNDTRIP_YEAR          9.739      0.134        9.500      10.000
REPAIR_DAYS             13.767     1.530        8.499      14.998
EARNING_DAYS            351.233    1.530        350.002    356.501
SAIL_OPENWATER    Hours 3652.439   52.159       3579.171   3807.415
IN_PORT           Hours 798.534    17.109       745.613    841.921
SAIL_ICE          Hours 3975.831   39.220       3829.026   4079.547
TIMEINSYSTEM      Hours 8429.583   36.731       8400.036   8556.021


         ** RESOURCE STATISTICS for scenario BASECASE **


Resource     Resource       Average   Standard    Standard     Average
Number       Label          Util.     Deviation   Error        Available


1           ICE_BREAKER      0.003       0.005       0.000        0.997
2           BESET            0.000       0.002       0.000        1.000
```

```
        ** AweSim! MULTIPLE RUN SUMMARY REPORT **
        Sun Aug 29 19:34:16 2004

  Simulation Project: CAPSTONE
  Modeller: SARAN
  Date: 11/7/2004
  Scenario: BASECASE - YOK - NEW YORK FAST SHIP (Arctic)
  Number of runs 300


         ** OBSERVED STATISTICS for scenario BASECASE **

Label           Units   Mean       Standard   Minimum     Maximum
                        Value      Deviation  Average     Average
                                              Value       Value

TOTAL_DISTANCE  NM     138191.267 1795.805    135985.000 143151.000
ROUNDTRIP_YEAR         8.521      0.111       8.385       8.827
REPAIR_DAYS            13.666     1.098       10.825      14.999
EARNING_DAYS           351.334    1.098       350.001     354.175
SAIL_OPENWATER Hours   4265.496   47.006      4110.680    4351.206
IN_PORT        Hours   704.950    22.863      627.139     757.384
SAIL_ICE       Hours   3454.409   51.852      3329.526    3647.639
TIMEINSYSTEM   Hours   8432.027   26.356      8400.016    8500.202

         ** RESOURCE STATISTICS for scenario BASECASE **

Resource     Resource      Average    Standard    Standard   Average
Number       Label         Util.      Deviation   Error      Available

1           ICE_BREAKER    0.002        0.004       0.000      0.998
2           BESET          0.000        0.000       0.000      1.000
```

```
        ** AweSim! MULTIPLE RUN SUMMARY REPORT **
        Mon Aug 30 10:53:00 2004

    Simulation Project: CAPSTONE
    Modeller: SARAN
    Date: 11/7/2004
    Scenario: BASECASE SLOW SHIP LINEAR OPTION(y=0.35x+4) YOK - St John's
                       (Arctic)
    Number of runs 300

          ** OBSERVED STATISTICS for scenario BASECASE **

       Label        Units     Mean      Standard      Minimum     Maximum
                              Value     Deviation     Average     Average
                                                      Value       Value

    TOTAL_DISTANCE    NM    92655.533   853.875      89199.000   94497.000
    ROUNDTRIP_YEAR           6.603      0.061         6.357       6.734
    REPAIR_DAYS             14.080      0.949        10.892      14.999
    EARNING_DAYS           350.920      0.949       350.001     354.108
    SAIL_OPENWATER  Hours  3836.685    30.564      3742.704    3942.290
    IN_PORT         Hours   461.489    11.143       424.778     490.168
    SAIL_ICE        Hours  4123.194    41.014      3935.538    4259.230

                   ** RESOURCE STATISTICS for scenario BASECASE **

    Resource       Resource     Average    Standard     Standard   Average
    Number         Label        Util.      Deviation    Error      Available

    1             ICE_BREAKER   0.001      0.004        0.000      0.999
    2             BESET         0.000      0.001        0.000      1.000
```

```
      ** AweSim! MULTIPLE RUN SUMMARY REPORT **
      Mon Aug 30 10:32:00 2004

 Simulation Project: CAPSTONE
 Modeller: SARAN
 Date: 11/7/2004
 Scenario: BASECASE SLOW SHIP LINEAR (y=0.35x+4) YOK - NY (Arctic)
 Number of runs 300


       ** OBSERVED STATISTICS for scenario BASECASE **

    Label        Units      Mean         Standard     Minimum      Maximum
                            Value        Deviation    Average      Average
                                                      Value        Value

TOTAL_DISTANCE   NM         81614.720    1189.574     78279.000    83901.000
ROUNDTRIP_YEAR              5.032        0.073        4.827        5.173
REPAIR_DAYS                 10.987       3.558        3.360        14.965
EARNING_DAYS                354.013      3.558        350.035      361.640
SAIL_OPENWATER   Hours      4511.311     106.262      4181.337     4774.444
IN_PORT          Hours      385.355      19.649       346.785      454.795
SAIL_ICE         Hours      3591.287     82.958       3423.728     3919.359


       ** RESOURCE STATISTICS for scenario BASECASE **

Resource     Resource        Average     Standard     Standard      Average
Number       Label           Util.       Deviation    Error         Available

1            ICE_BREAKER     0.001        0.005        0.000         0.999
2            BESET           0.000        0.001        0.000         1.000
```

```
         ** AweSim! MULTIPLE RUN SUMMARY REPORT **
         Mon Aug 30 10:43:01 2004

   Simulation Project: CAPSTONE
   Modeller: SARAN
   Date: 11/7/2004
   Scenario BASECASE SLOW SHIP DIFFICULT
   (y=0.0022*x^3-  0.0397*x^2+0.2834*x+3.5729)YOK- St John's (Arctic)
   Number of runs 300

          ** OBSERVED STATISTICS for scenario BASECASE **

        Label         Units    Mean      Standard     Minimum      Maximum
                               Value     Deviation    Average      Average
                                                      Value        Value

  TOTAL_DISTANCE       NM    70572.970   1638.738     66056.000    72971.000
  ROUNDTRIP_YEAR              5.029      0.117        4.708        5.200
  REPAIR_DAYS                 10.744     3.388        3.413        14.963
  EARNING_DAYS                354.256    3.388        350.037      361.587
  SAIL_OPENWATER     Hours    3460.617   149.076      3118.388     3737.375
  IN_PORT            Hours    387.786    21.246       347.206      444.013
  SAIL_ICE           Hours    4648.818   129.724      4342.148     5014.751


          ** RESOURCE STATISTICS for scenario BASECASE **

  Resource      Resource     Average     Standard    Standard    Average
  Number        Label        Util.       Deviation   Error       Available

  1             ICE_BREAKER   0.001       0.005       0.000       0.999
  2             BESET         0.000       0.001       0.000       1.000
```

```
        ** AweSim! MULTIPLE RUN SUMMARY REPORT **
        Mon Aug 30 10:36:28 2004

   Simulation Project: CAPSTONE
   Modeller: SARAN
   Date: 11/7/2004
   Scenario: BASECASE
   SLOW SHIP DIFFICULT (y=0.0022*x^3-0.0397*x^2+0.2834*x+3.5729) YOK-NY
   (Arctic)
   Number of runs 300

          ** OBSERVED STATISTICS for scenario BASECASE **

      Label          Units    Mean       Standard     Minimum     Maximum
                              Value      Deviation    Average     Average
                                                       Value       Value

  TOTAL_DISTANCE      NM     72292.483    1629.256    68701.000
  76008.000
  ROUNDTRIP_YEAR              4.458       0.100       4.236       4.687
  REPAIR_DAYS                 12.378      2.049       7.508       14.963
  EARNING_DAYS                352.622     2.049       350.037     357.492
  SAIL_OPENWATER     Hours    3976.363    115.532     3778.393    4241.076
  IN_PORT            Hours    340.558     17.204      303.698     402.053
  SAIL_ICE           Hours    4142.345    117.166     3805.749    4417.507

             ** RESOURCE STATISTICS for scenario BASECASE **

  Resource       Resource       Average     Standard     Standard     Average
  Number         Label          Util.       Deviation    Error        Available

  1              ICE_BREAKER    0.001       0.003        0.000        0.999
  2              BESET          0.000       0.000        0.000        1.000
```

```
        ** AweSim! MULTIPLE RUN SUMMARY REPORT **
        Mon Aug 30 20:06:12 2004

  Simulation Project: CAPSTONE
  Modeler: SARAN
  Date: 11/7/2004
  Scenario: BASECASE FAST SHIP PANAMA CANAL YOK - NEW YORK
  Number of runs 300

         ** OBSERVED STATISTICS for scenario BASECASE **

     Label          Units   Mean       Standard      Minimum      Maximum
                            Value      Deviation     Average      Average
                                                     Value        Value

TOTALDISTANCE     NM     146499.167  331.245       145470.000  147470.000
TIMEINSYSTEM      Hours  8646.497    3.789         8640.076    8654.298
CANAL_TIME        Hours  294.557     5.786         276.378     311.303
EARNING_DAYS             360.271     0.158         360.003     360.596
ROUND_TRIP               7.553       0.017         7.500       7.603
SAIL_TIME         Hours  7721.959    14.682        7684.546    7760.298
IN_PORT           Hours  629.981     13.647        592.520     667.666


  Simulation Project: CAPSTONE
  Modeller: SARAN
  Date: 11/7/2004
  Scenario: BASECASE FAST SHIP PANAMA CANAL YOK -St John's
  Number of runs 300

         ** OBSERVED STATISTICS for scenario BASECASE **

     Label          Units   Mean       Standard      Minimum      Maximum
                            Value      Deviation     Average      Average
                                                      Value        Value

TOTALDISTANCE      NM      147671.667     338.248   146910.000   148410.000
TIMEINSYSTEM      Hours    8646.558       3.845     8640.012     8654.181
CANAL_TIME        Hours    275.386        5.991     253.421      293.246
EARNING_DAYS               360.273        0.160     360.000      360.591
ROUND_TRIP                 7.083          0.016     7.047        7.119
SAIL_TIME         Hours    7783.827       14.311    7742.395     7829.989
IN_PORT           Hours    587.345        12.120    547.402      619.448
```

```
Simulation Project: CAPSTONE
Modeller: SARAN
Date: 11/7/2004
Scenario: BASECASE     SLOW SHIP PANAMA CANAL YOK - NEW YORK
Number of runs 300

      ** OBSERVED STATISTICS for scenario BASECASE **

     Label       Units      Mean        Standard       Minimum      Maximum
                            Value       Deviation      Average      Average
                                                       Value        Value

TOTALDISTANCE  NM        85400.053      166.185      85084.000    86032.000
TIMEINSYSTEM   Hours      8651.394        6.536       8640.041     8664.511
CANAL_TIME     Hours       172.944        7.921        149.957      186.908
EARNING_DAYS               360.475        0.272        360.002      361.021
ROUND_TRIP                   4.403        0.009          4.387        4.436
SAIL_TIME      Hours      8142.829       11.992       8108.018     8174.873
IN_PORT        Hours       335.621        9.987        307.887      361.246
```

```
Simulation Project: CAPSTONE
Modeller: SARAN
Date: 11/7/2004
Scenario: BASECASE  SLOW SHIP PANAMA CANAL YOK - St John's

Number of runs 300

      ** OBSERVED STATISTICS for scenario BASECASE **

     Label      Units        Mean         Standard       Minimum      Maximum
                             Value        Deviation      Average      Average
                                                         Value        Value

TOTALDISTANCE   NM        85575.000       218.060      85020.000
86270.000
TIMEINSYSTEM   Hours       8652.446         7.004       8640.028     8664.538
CANAL_TIME     Hours        156.878         4.140        147.194      167.159
EARNING_DAYS                360.519         0.292        360.001      361.022
ROUND_TRIP                    4.105         0.010          4.078        4.138
SAIL_TIME      Hours       8159.842        13.621       8126.103     8200.497
IN_PORT        Hours        335.726        10.240        305.754      369.174
```

Appendix 11

System Model - Economic Simualtion

Yokohama - SJ panama Route.

Distance	147671.7	Freight rate	1297.5	
Round trip	7.08	Time_in_system		8646.5
Sail_Open_Water	7783.8	Resource Utilisation		0
Sail_ ice		Port_stay		587.35
canal_time	275.39	Repair_days		5
		Scaling_factor_capital		1
		Scaling_factor_premiums		1

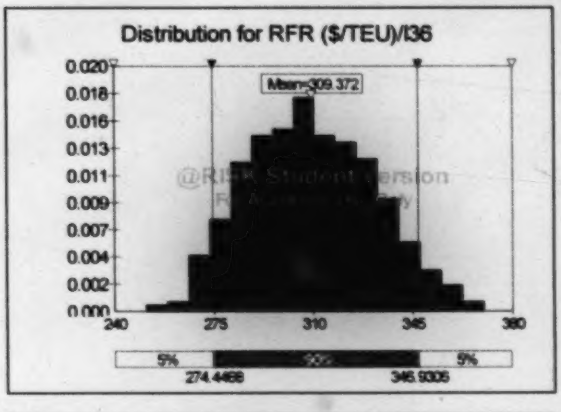
Item (Units)	Panama		
Voyage Cost		**Operating cost**	
Power Demand_Openwater(Kw)	20790	Management_fee	1131500
Power Demand_ice(Kw)	44100	Drydock_cost	350000
Specific_fuel_cons_M/E(g/Kwh)	165.5	Steel_Work_cost($/Ton)	0
Specific_fuel_cons_canal(Tons/hr)	2.4	Steel_work_Qty(Tons)	0
Specific_fuel_cons_A/E(Tons/hr)	0.1	Total_Steel_work_cost($)	0
A/E_fuelcons_open water(Tons)	778.38	Total_Drydock_cost($)	350000
A/E_fuelcons_ice/canal(Tons)	55.078	H&M_Premium($)	175000
A/E_fuelcons_port/repair(Tons)	70.735	P&I_Premium($)	125000
M/E_fuelcons_open water(Tons)	26782.07	Total_Operating_Cost ($)	1781500
M/E_fuelcons_canal/ice(Tons)	660.94		
Total_fuelcons(Tons)	28347.20		
Price_bunker($/Ton)	183.3	**Capital Cost**	
Total_fuel_cost ($)	5196041.75	New_ Building _Price($)	42000000
Canal/icebreaker_Tarif	113010	Interest_rate(i)	0.09
Canal/icebreaker_dues($)	1600221.6	Age_ship(n)	25.5
Specific_Cyl_LO_cons(Ltrs/Kwh)	1	CRF ($/year)	4252337.013
Cyl_LO_cons_Openwater(Ltrs)	161825.20		
Cyl_LO_cons_canal/ice(Ltrs)	2862.67905	Total_Cost ($)	13136038.45
Total_Cyl_LO_cons(Ltrs)	164687.88		
Sp_M/E_LO_cons(Ltrs/hr)openwater	1.5	RFR ($/TEU)	309.228777
Sp_M/E_LO_cons(Ltrs/hr)ice	3		
M/E_LO_Cons_openwater(Ltrs)	11675.7	RFR_Run($/TEU)	209.1266816
M/E_LO_Cons_ice/canal(Ltrs)	0		
Total_M/E_LO_cons(Ltrs)	11675.7	Sp_Trans_Cost($/NM)	0.002094029
Total_A/E_LO_cons(Ltrs)	3600		
Total_Luboil_Consumption(Ltrs)	179963.58	Running_cost	8883701.44
Unit_Price_Luboil($/Ton)	1.7		
Total_Cost_Luboil($)	305938.09	Cost/unit revenue	0.2383
Total_ Voyage_Cost	7102201.44		

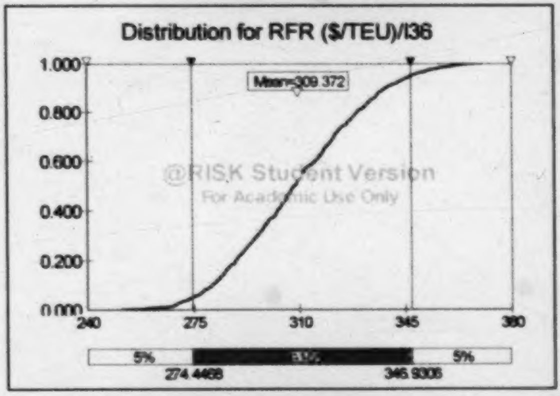
Appendix 12

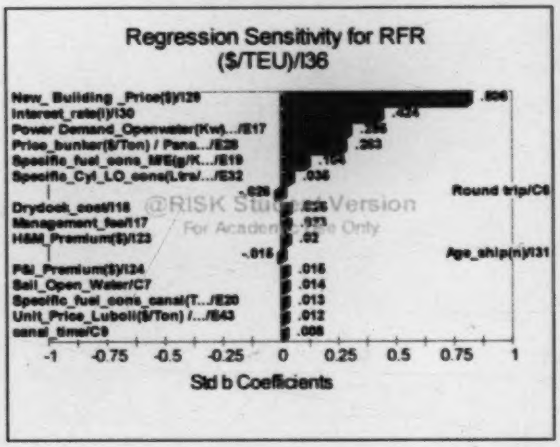
Economic Performance Simulation reports

Pages 133 to 149

Simulation Results for YOK- SJ
RFR ($/TEU) / I36





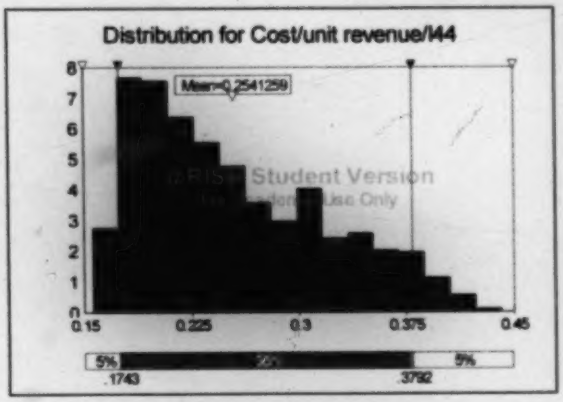


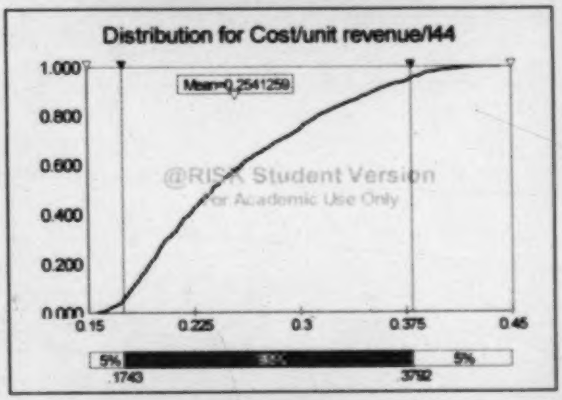
Summary Information	
Workbook Name	nput &System Models- Eco
Number of Simulations	1
Number of Iterations	1000
Number of Inputs	22
Number of Outputs	2
Sampling Type	Latin Hypercube
Simulation Start Time	09/09/2004 8:02
Simulation Stop Time	09/09/2004 8:02
Simulation Duration	00:00:02
Random Seed	635487797

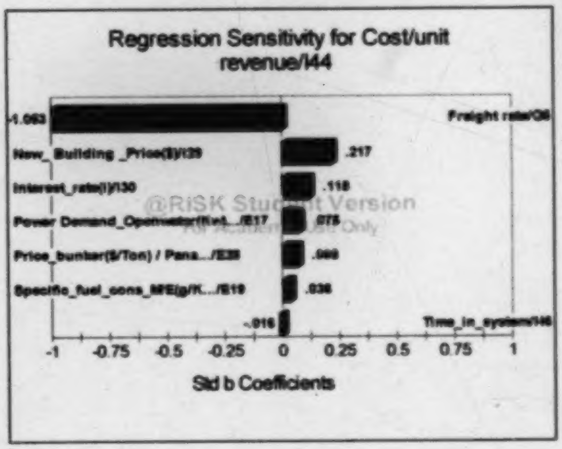
Summary Statistics			
Statistic	Value	%tile	Value
Minimum	251.1180725	5%	274.4468079
Maximum	370.3243713	10%	280.9006042
Mean	309.3720317	15%	285.0541382
Std Dev	22.27856127	20%	288.7786724
Variance	496.3342924	25%	292.2429199
Skewness	0.154920668	30%	296.1358032
Kurtosis	2.463976069	35%	298.9877625
Median	308.138916	40%	302.833252
Mode	321.7882599	45%	305.6478271
Left X	274.4468079	50%	308.138916
Left P	5%	55%	311.1478577
Right X	346.930603	60%	315.2830505
Right P	95%	65%	318.3118896
Diff X	72.48379517	70%	321.6373596
Diff P	90%	75%	325.6268311
#Errors	0	80%	329.254303
Filter Min		85%	333.9180603
Filter Max		90%	338.7140503
#Filtered	0	95%	346.930603

Sensitivity			
Rank	Name	Regr	Corr
#1	New_ Building _P	0.804	0.814
#2	Interest_rate(i) / $	0.424	0.391
#3	Power Demand_(	0.285	0.282
#4	Price_bunker($/T(	0.264	0.228
#5	Specific_fuel_con	0.103	0.070
#6	Specific_Cyl_LO_	0.035	0.043
#7	Drydock_cost / $I	0.027	0.493
#8	Round trip / C6	-0.025	-0.079
#9	H&M_Premium($	0.020	-0.034
#10	P&I_Premium($) /	0.014	0.033
#11	Sail_Open_Wate	0.014	-0.044
#12	Specific_fuel_con	0.013	-0.048
#13	Distance / C5	0.000	-0.066
#14	Freight rate / G	0.000	0.416
#15	Time_in_system /	0.000	0.070
#16	Repair_days / $H	0.000	-0.031

Simulation Results for YOK - SJ Panama Route
Cost/unit revenue / I44





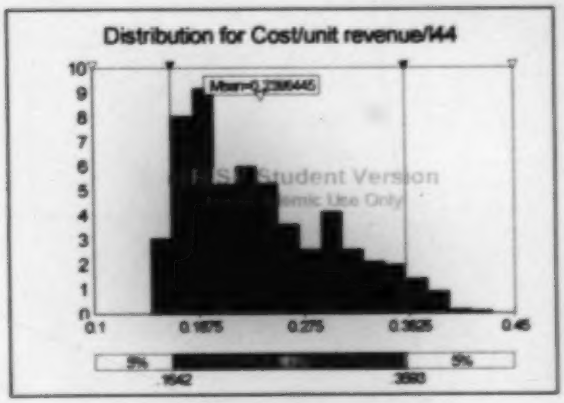


Summary Information	
Workbook Name	nput &System Models- Ec
Number of Simulations	1
Number of Iterations	1000
Number of Inputs	22
Number of Outputs	2
Sampling Type	Latin Hypercube
Simulation Start Time	09/09/2004 8:02
Simulation Stop Time	09/09/2004 8:02
Simulation Duration	00:00:02
Random Seed	635487797

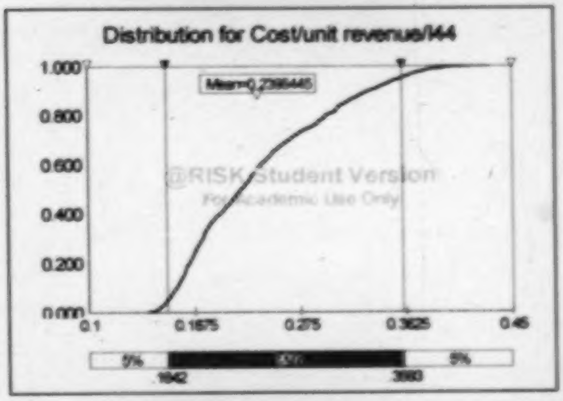
Summary Statistics			
Statistic	Value	%tile	Value
Minimum	0.1580	5%	0.1743
Maximum	0.4419	10%	0.1808
Mean	0.2541	15%	0.1869
Std Dev	0.0650	20%	0.1938
Variance	0.004230511	25%	0.1993
Skewness	0.641407192	30%	0.2059
Kurtosis	2.41229202	35%	0.2134
Median	0.2384	40%	0.2219
Mode	0.2133	45%	0.2295
Left X	0.1743	50%	0.2384
Left P	5%	55%	0.2488
Right X	0.3792	60%	0.2592
Right P	95%	65%	0.2733
Diff X	0.2048	70%	0.2866
Diff P	90%	75%	0.3015
#Errors	0	80%	0.3143
Filter Min		85%	0.3330
Filter Max		90%	0.3533
#Filtered	0	95%	0.3792

Sensitivity			
Rank	Name	Regr	Corr
#1	Freight rate / $G	-1.053	-0.962
#2	New_ Building _P	0.217	-0.353
#3	Interest_rate(i) /	0.118	0.130
#4	Power Demand_	0.075	0.114
#5	Price_bunker($/T	0.068	0.061
#6	Specific_fuel_con	0.036	0.079
#7	Time_in_system	-0.018	-0.016
#8	Port_stay / H8	0.000	-0.034
#9	canal_time / C	0.000	0.033
#10	Repair_days / $H	0.000	0.030
#11	Management_fee	0.000	0.041
#12	Power Demand_	0.000	0.044
#13	Drydock_cost / $	0.000	0.112
#14	Age_ship(n) / I	0.000	0.020
#15	Specific_Cyl_LO_	0.000	0.031
#16	Unit_Price_Lubo	0.000	0.028

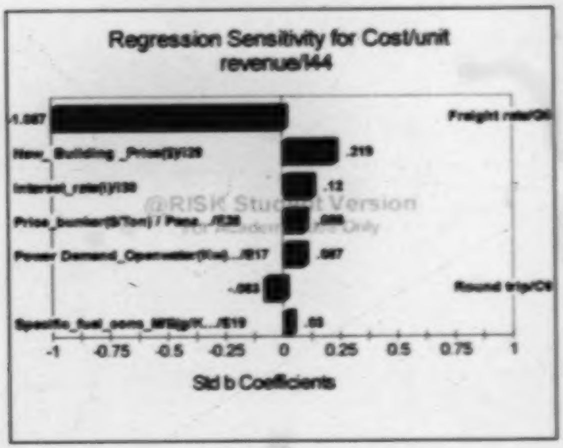
Simulation Results for YOK -NY Panama Route
Cost/unit revenue / I44



Summary Information	
Workbook Name	nput &System Models- Eco
Number of Simulations	1
Number of Iterations	1000
Number of Inputs	22
Number of Outputs	2
Sampling Type	Latin Hypercube
Simulation Start Time	09/09/2004 7:44
Simulation Stop Time	09/09/2004 7:44
Simulation Duration	00:00:01
Random Seed	1109588159

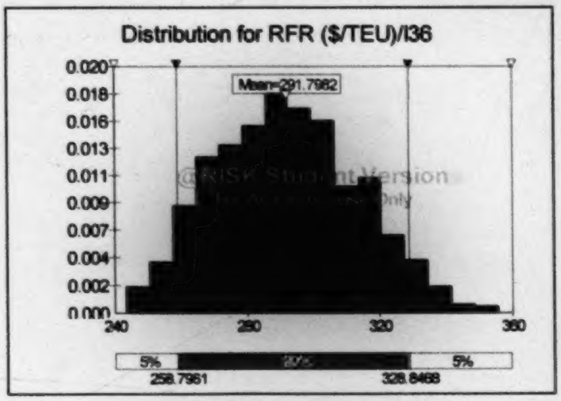


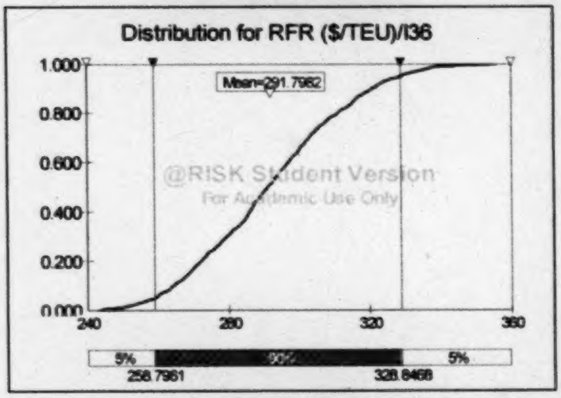
Summary Statistics			
Statistic	Value	%tile	Value
Minimum	0.1473	5%	0.1642
Maximum	0.4321	10%	0.1718
Mean	0.2386	15%	0.1778
Std Dev	0.0615	20%	0.1830
Variance	0.003782586	25%	0.1881
Skewness	0.703692652	30%	0.1945
Kurtosis	2.554119491	35%	0.1993
Median	0.2265	40%	0.2080
Mode	0.1954	45%	0.2177
Left X	0.1642	50%	0.2265
Left P	5%	55%	0.2347
Right X	0.3583	60%	0.2428
Right P	95%	65%	0.2533
Diff X	0.1942	70%	0.2671
Diff P	90%	75%	0.2843
#Errors	0	80%	0.2971
Filter Min		85%	0.3139
Filter Max		90%	0.3329
#Filtered	0	95%	0.3583

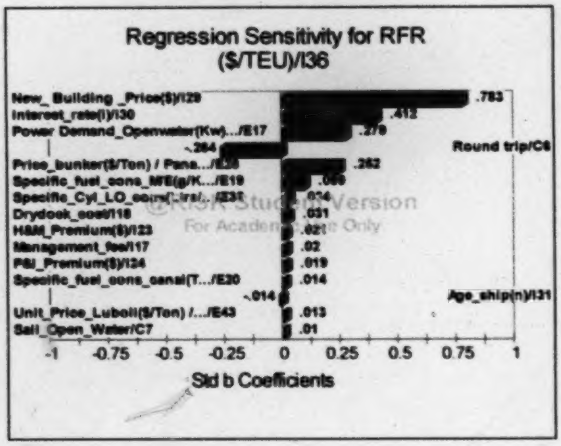


Sensitivity			
Rank	Name	Regr	Corr
#1	Freight rate / $C6	-1.056	-0.951
#2	New_ Building _P	0.219	-0.403
#3	Interest_rate(i) / $	0.120	0.146
#4	Price_bunker($/T	0.090	0.086
#5	Power Demand_(	0.086	0.071
#6	Round trip / C9	-0.083	-0.108
#7	Distance / C5	0.000	0.041
#8	Sail_Open_Water	0.000	0.036
#9	Port_stay / H8	0.000	-0.073
#10	Management_fee	0.000	0.054
#11	Power Demand_i	0.000	0.042
#12	Drydock_cost / $I	0.000	0.129
#13	Specific_fuel_con	0.000	0.024
#14	H&M_Premium($	0.000	-0.034
#15	Age_ship(n) / $B	0.000	-0.026
#16	Specific_Cyl_LO	0.000	-0.039

Simulation Results for YOK -NY Panama Route
RFR ($/TEU) / I36







Summary Information

Workbook Name	nput &System Models- Eco
Number of Simulations	1
Number of Iterations	1000
Number of Inputs	22
Number of Outputs	2
Sampling Type	Latin Hypercube
Simulation Start Time	09/09/2004 7:44
Simulation Stop Time	09/09/2004 7:44
Simulation Duration	00:00:01
Random Seed	1109588159

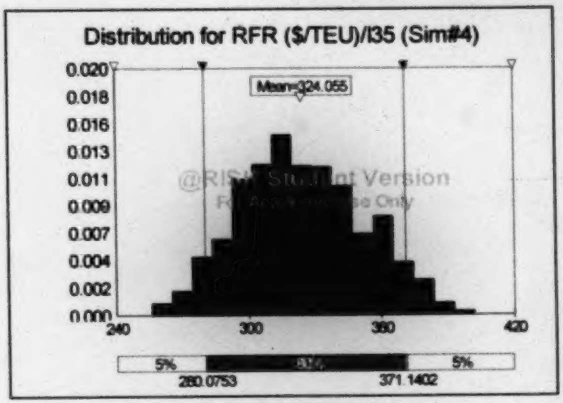
Summary Statistics

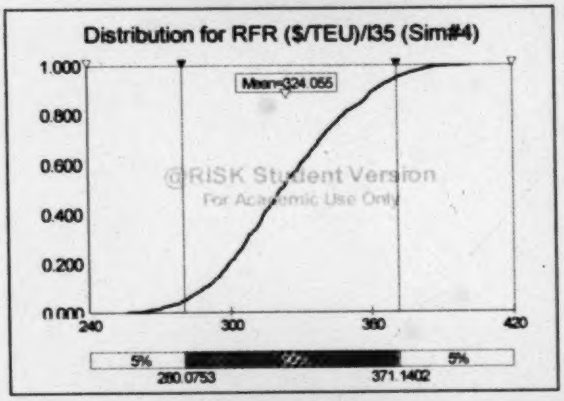
Statistic	Value	%tile	Value
Minimum	243.3322449	5%	258.7961426
Maximum	356.0644226	10%	263.6961975
Mean	291.7982411	15%	268.4133606
Std Dev	21.42652868	20%	271.9672546
Variance	459.0961315	25%	275.725708
Skewness	0.182385771	30%	279.2947998
Kurtosis	2.554842778	35%	283.1399841
Median	290.980835	40%	285.6332397
Mode	295.53125	45%	288.1590576
Left X	258.7961426	50%	290.980835
Left P	5%	55%	293.7849426
Right X	328.8467712	60%	296.8464661
Right P	95%	65%	299.8415222
Diff X	70.05062866	70%	302.8881836
Diff P	90%	75%	306.1125488
#Errors	0	80%	310.9806519
Filter Min		85%	315.5930176
Filter Max		90%	320.7780762
#Filtered	0	95%	328.8467712

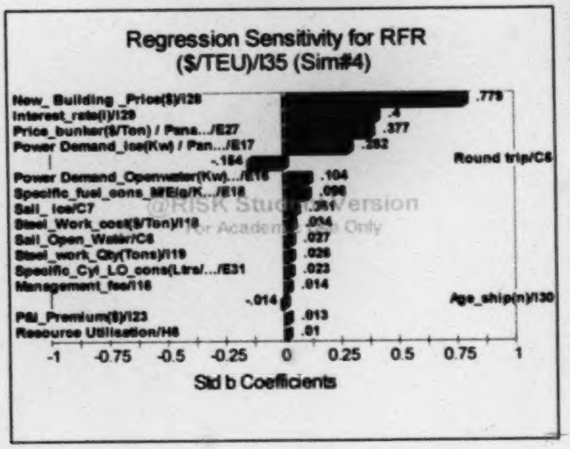
Sensitivity

Rank	Name	Regr	Corr
#1	New_ Building _P	0.780	0.787
#2	Interest_rate(i) / $	0.413	0.367
#3	Power Demand_	0.281	0.286
#4	Round trip / C6	-0.261	-0.170
#5	Price_bunker($/T	0.251	0.254
#6	Specific_fuel_con	0.100	0.104
#7	Drydock_cost / $I	0.031	0.446
#8	H&M_Premium($	0.020	0.029
#9	P&I_Premium($)	0.019	0.060
#10	Specific_fuel_con	0.015	0.013
#11	Age_ship(n) / I	-0.014	-0.018
#12	Repair_days / $H	0.005	0.038
#13	Freight rate / G	0.000	0.440
#14	Time_in_system	0.000	0.043
#15	Port_stay / H8	0.000	0.021
#16	Power Demand_	0.000	-0.027

Simulation Results for Yok-NY Arctic
RFR ($/TEU) / I35 / Simulation 4 Scaling 1.4





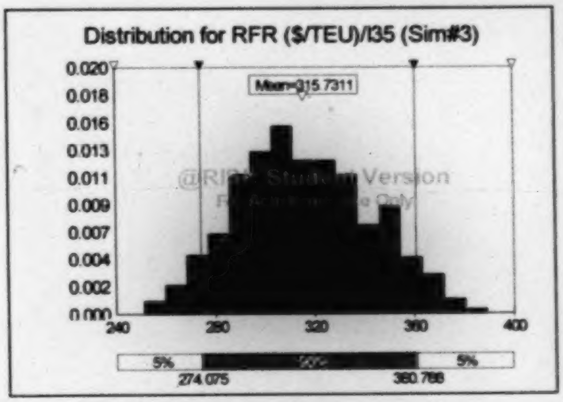


Summary Information	
Workbook Name	spread sheet model.xls
Number of Simulations	4
Number of Iterations	1000
Number of Inputs	25
Number of Outputs	1
Sampling Type	Latin Hypercube
Simulation Start Time	07/09/2004 16:00
Simulation Stop Time	07/09/2004 16:00
Simulation Duration	00:00:08
Random Seed	2107786879

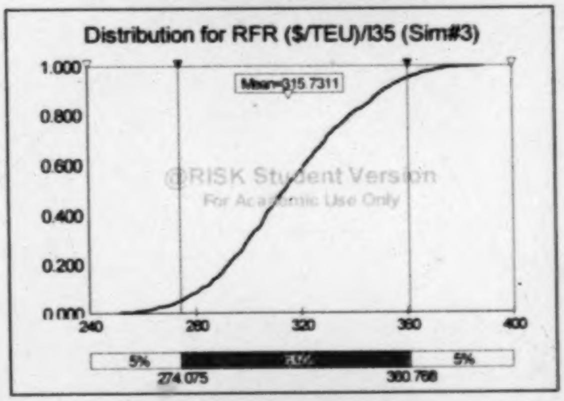
Summary Statistics			
Statistic	Value	%tile	Value
Minimum	255.9195251	5%	280.0753174
Maximum	402.5669861	10%	288.1418457
Mean	324.0550196	15%	295.1685181
Std Dev	27.84881162	20%	299.397644
Variance	775.5563086	25%	304.0644226
Skewness	0.170302603	30%	307.1508789
Kurtosis	2.490028414	35%	311.7118835
Median	321.868988	40%	314.5342407
Mode	313.2050079	45%	318.3454285
Left X	280.0753174	50%	321.868988
Left P	5%	55%	326.1427612
Right X	371.1401978	60%	330.2060547
Right P	95%	65%	334.4779053
Diff X	91.06488037	70%	338.8831177
Diff P	90%	75%	343.596405
#Errors	0	80%	348.8362122
Filter Min		85%	356.7031555
Filter Max		90%	362.2235718
#Filtered	0	95%	371.1401978

Sensitivity			
Rank	Name	Regr	Corr
#1	New_ Building _P	0.778	0.764
#2	Interest_rate(i) / $	0.402	0.359
#3	Price_bunker($/T	0.378	0.379
#4	Power Demand_i	0.280	0.271
#5	Round trip / C5	-0.151	-0.040
#6	Power Demand_(	0.107	0.085
#7	Specific_fuel_con	0.097	0.057
#8	Steel_Work_cost	0.031	-0.035
#9	Management_fee	0.014	0.130
#10	P&I_Premium($)	0.011	0.170
#11	Time_in_system	0.000	-0.035
#12	Port_stay / H7	0.000	0.073
#13	Repair_days / $H	0.000	0.054
#14	Drydock_cost / $	0.000	0.473
#15	H&M_Premium($	0.000	0.558
#16	Unit_Price_Lubol	0.000	0.038

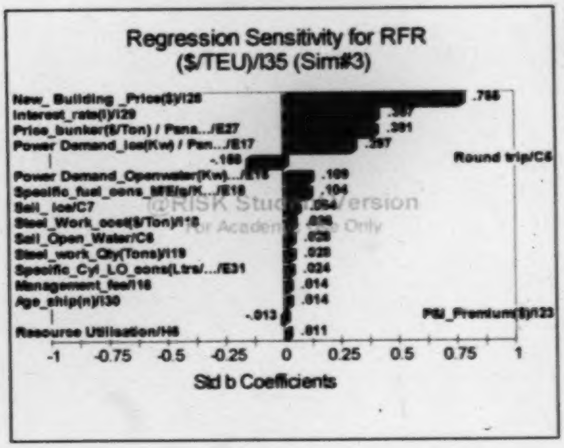
Simulation Results for Yok-NY Arctic
RFR ($/TEU) / I35 / Simulation 3 Scaling 1.3



Summary Information	
Workbook Name	spread sheet model.xls
Number of Simulations	4
Number of Iterations	1000
Number of Inputs	25
Number of Outputs	1
Sampling Type	Latin Hypercube
Simulation Start Time	07/09/2004 16:00
Simulation Stop Time	07/09/2004 16:00
Simulation Duration	00:00:08
Random Seed	2107786879

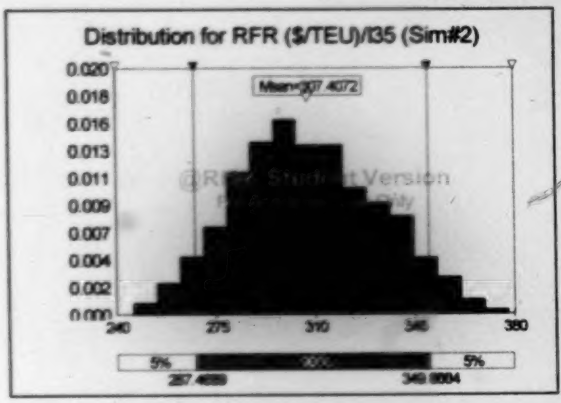


Summary Statistics			
Statistic	Value	%tile	Value
Minimum	251.0528259	5%	274.0750122
Maximum	389.635498	10%	281.9614563
Mean	315.731093	15%	288.5376587
Std Dev	26.419699	20%	292.5964355
Variance	698.0004954	25%	296.9537964
Skewness	0.163313543	30%	300.0535889
Kurtosis	2.511449458	35%	303.9999695
Median	314.1116333	40%	306.7649841
Mode	305.7007568	45%	310.3573303
Left X	274.0750122	50%	314.1116333
Left P	5%	55%	317.6000061
Right X	360.7680359	60%	321.7137756
Right P	95%	65%	325.5645142
Diff X	86.69302368	70%	329.6567688
Diff P	90%	75%	334.4376221
#Errors	0	80%	339.49823
Filter Min		85%	346.555542
Filter Max		90%	351.8218994
#Filtered	0	95%	360.7680359

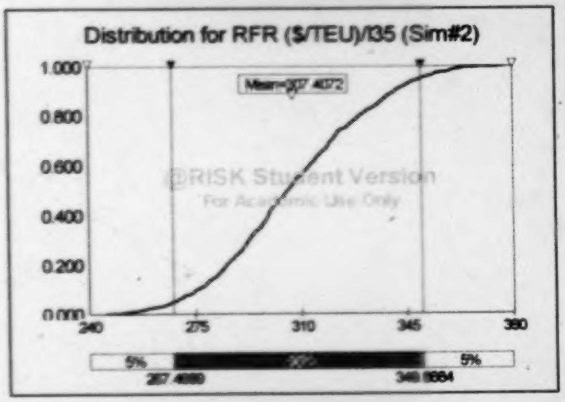


Sensitivity			
Rank	Name	Regr	Corr
#1	New_ Building _P	0.764	0.749
#2	Price_bunker($/T	0.398	0.399
#3	Interest_rate(i) / $	0.393	0.354
#4	Power Demand_i	0.296	0.284
#5	Round trip / C5	-0.157	-0.044
#6	Power Demand_(	0.110	0.090
#7	Specific_fuel_con	0.104	0.062
#8	Sail_ ice / C7	0.052	0.034
#9	Steel_Work_cost	0.032	-0.034
#10	Management_fee	0.014	0.127
#11	P&I_Premium($)	0.012	0.168
#12	Unit_Price_Lubo	0.007	0.037
#13	Port_stay / H7	0.000	0.072
#14	Repair_days / $H	0.000	0.052
#15	Drydock_cost / $I	0.000	0.464
#16	H&M_Premium($	0.000	0.547

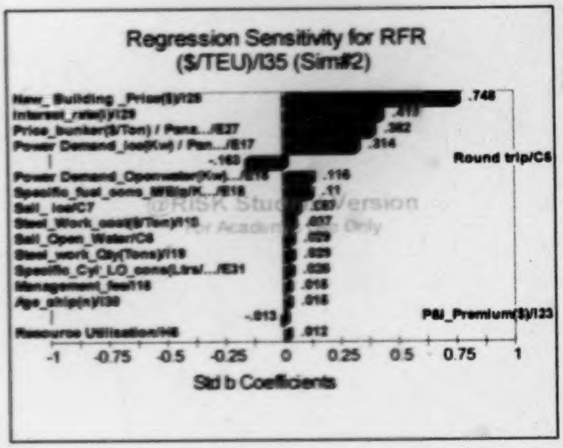
Simulation Results for Yok-NY Arctic
RFR ($/TEU) / I35 / Simulation 2 Scaling 1.2



Summary Information	
Workbook Name	spread sheet model.xls
Number of Simulations	4
Number of Iterations	1000
Number of Inputs	25
Number of Outputs	1
Sampling Type	Latin Hypercube
Simulation Start Time	07/09/2004 16:00
Simulation Stop Time	07/09/2004 16:00
Simulation Duration	00:00:08
Random Seed	2107786879

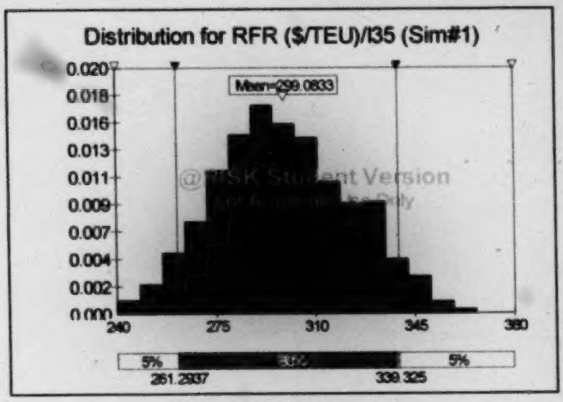


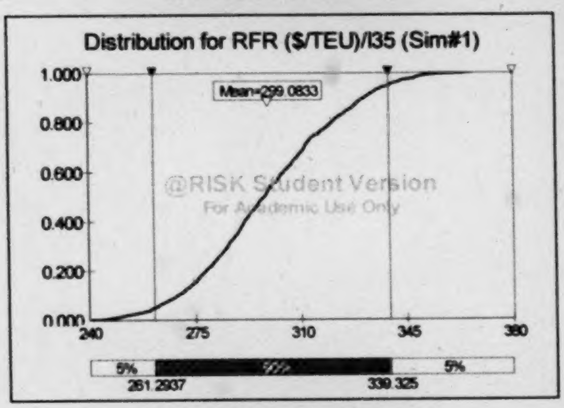
Summary Statistics			
Statistic	Value	%tile	Value
Minimum	245.7639465	5%	267.4689331
Maximum	378.2530212	10%	275.1775208
Mean	307.4071665	15%	281.6710815
Std Dev	25.01808081	20%	285.1837158
Variance	625.9043672	25%	289.4989319
Skewness	0.155622711	30%	292.9069824
Kurtosis	2.534667813	35%	296.7240295
Median	305.9253845	40%	299.2678528
Mode	291.9586121	45%	302.2227783
Left X	267.4689331	50%	305.9253845
Left P	5%	55%	309.1199646
Right X	349.8884277	60%	313.2132263
Right P	95%	65%	316.6788635
Diff X	82.41949463	70%	320.6025696
Diff P	90%	75%	325.1938171
#Errors	0	80%	329.7746277
Filter Min		85%	336.0484924
Filter Max		90%	341.6226807
#Filtered	0	95%	349.8884277

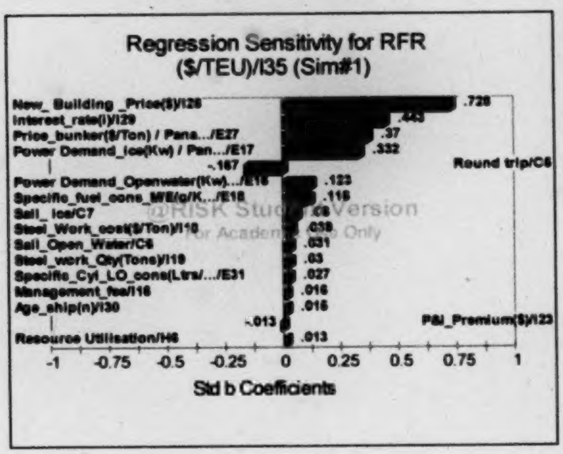


Sensitivity			
Rank	Name	Regr	Corr
#1	New_ Building _P	0.747	0.732
#2	Price_bunker($/T	0.421	0.421
#3	Interest_rate(i) / $	0.383	0.348
#4	Power Demand_i	0.313	0.298
#5	Round trip / C5	-0.161	-0.048
#6	Power Demand_C	0.116	0.096
#7	Specific_fuel_con	0.110	0.067
#8	Sail_ ice / C7	0.055	0.037
#9	Steel_Work_cost	0.034	-0.034
#10	Management_fee	0.015	0.122
#11	P&I_Premium($)	0.013	0.166
#12	Unit_Price_Lubol	0.007	0.035
#13	Port_stay / H7	0.000	0.071
#14	Repair_days / $H	0.000	0.050
#15	Drydock_cost / $I	0.000	0.453
#16	H&M_Premium($	0.000	0.535

Simulation Results for Yok-NY Arctic
RFR ($/TEU) / I35 / Simulation 1Scaling 1.1





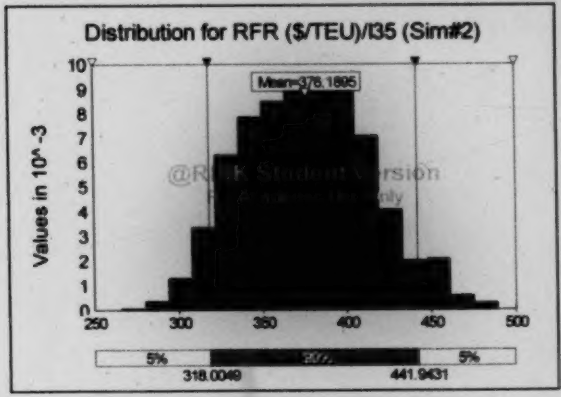


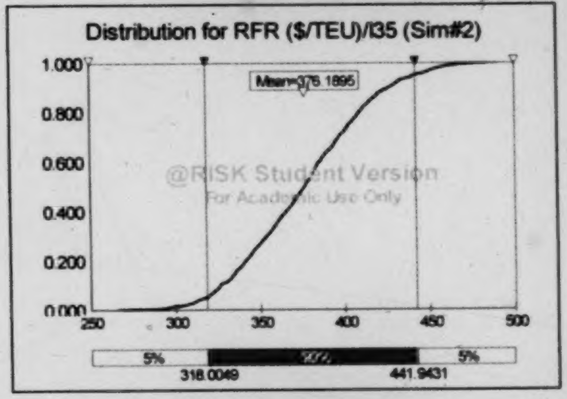
Summary Information	
Workbook Name	spread sheet model.xls
Number of Simulations	4
Number of Iterations	1000
Number of Inputs	25
Number of Outputs	1
Sampling Type	Latin Hypercube
Simulation Start Time	07/09/2004 16:00
Simulation Stop Time	07/09/2004 16:00
Simulation Duration	00:00:08
Random Seed	2107786879

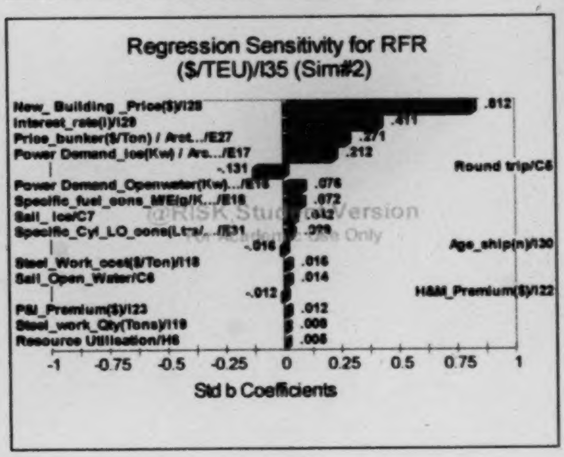
Summary Statistics			
Statistic	Value	%tile	Value
Minimum	240.2051544	5%	261.2937317
Maximum	366.8786011	10%	269.0808105
Mean	299.0832396	15%	274.3973389
Std Dev	23.64884685	20%	278.2320862
Variance	559.2679572	25%	282.2235718
Skewness	0.147216353	30%	285.6739807
Kurtosis	2.559413284	35%	288.8778076
Median	297.8696289	40%	291.1740112
Mode	298.6352783	45%	294.4648743
Left X	261.2937317	50%	297.8696289
Left P	5%	55%	300.6098328
Right X	339.3249512	60%	304.3273621
Right P	95%	65%	307.7669678
Diff X	78.03121948	70%	311.4187012
Diff P	90%	75%	314.8164368
#Errors	0	80%	320.6154175
Filter Min		85%	325.9837341
Filter Max		90%	331.4256592
#Filtered	0	95%	339.3249512

Sensitivity			
Rank	Name	Regr	Corr
#1	New_ Building _P	0.728	0.712
#2	Price_bunker($/T	0.445	0.445
#3	Interest_rate(i) / $	0.371	0.340
#4	Power Demand_i	0.331	0.314
#5	Round trip / C5	-0.166	-0.052
#6	Power Demand_C	0.122	0.102
#7	Specific_fuel_con	0.116	0.073
#8	Sail_ ice / C7	0.059	0.041
#9	Steel_Work_cost	0.038	-0.033
#10	Steel_work_Qty(T	0.031	0.033
#11	Management_fee	0.016	0.117
#12	P&I_Premium($)	0.013	0.164
#13	Port_stay / H7	0.000	0.070
#14	Repair_days / $H	0.000	0.047
#15	Drydock_cost / $I	0.000	0.441
#16	H&M_Premium($	0.000	0.519

Simulation Results for Yokohama - New York Arctic Route
RFR ($/TEU) Simulation 2 Scale Factor = 2.0





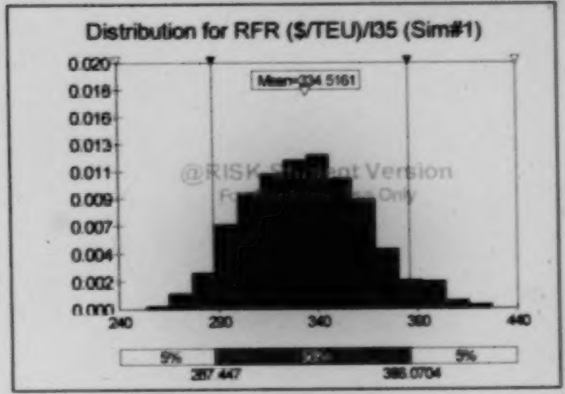


Summary Information	
Workbook Name	spread sheet model.xls
Number of Simulations	2
Number of Iterations	1000
Number of Inputs	25
Number of Outputs	5
Sampling Type	Latin Hypercube
Simulation Start Time	07/09/2004 13:15
Simulation Stop Time	07/09/2004 13:16
Simulation Duration	00:00:06
Random Seed	1210208572

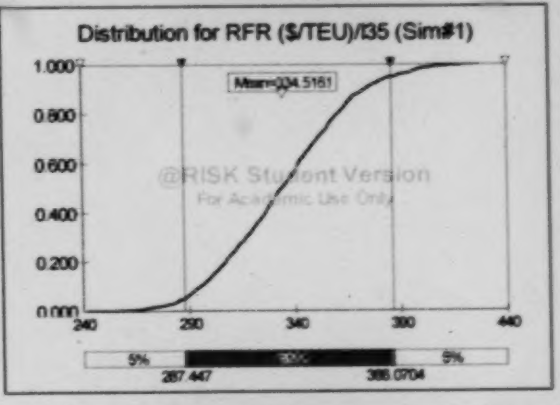
Summary Statistics			
Statistic	Value	%tile	Value
Minimum	265.7413025	5%	318.0049133
Maximum	489.8200073	10%	325.9797974
Mean	376.1894749	15%	334.5498047
Std Dev	38.18294172	20%	340.8153076
Variance	1457.937039	25%	346.8473511
Skewness	0.157874588	30%	353.5158081
Kurtosis	2.63938853	35%	359.5677185
Median	375.8647156	40%	365.1192932
Mode	370.2272675	45%	370.3795471
Left X	318.0049133	50%	375.8647156
Left P	5%	55%	381.0412598
Right X	441.9431152	60%	384.6085815
Right P	95%	65%	391.616272
Diff X	123.9382019	70%	396.6308899
Diff P	90%	75%	402.3532715
#Errors	0	80%	408.4080505
Filter Min		85%	415.8612671
Filter Max		90%	426.2546692
#Filtered	0	95%	441.9431152

Sensitivity			
Rank	Name	Regr	Corr
#1	New_ Building _P	0.792	0.825
#2	Interest_rate(i) / $	0.410	0.409
#3	Price_bunker($/T	0.272	0.281
#4	Power Demand_I	0.213	0.186
#5	Round trip / C5	-0.132	-0.098
#6	Power Demand_O	0.077	0.102
#7	Specific_fuel_con	0.073	0.117
#8	Steel_Work_cost	0.017	0.149
#9	P&I_Premium($)	0.014	0.161
#10	Age_ship(n) / I	-0.014	-0.041
#11	Drydock_cost / $I	0.011	0.507
#12	Distance / C4	0.000	0.058
#13	Repair_days / $H	0.000	0.045
#14	Management_fee	0.000	0.151
#15	Specific_fuel_con	0.000	-0.026
#16	H&M_Premium($	0.000	0.617

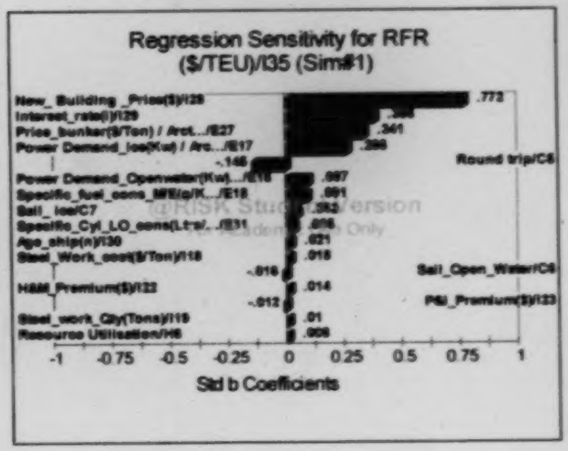
Simulation Results for Yokohama - New York Arctic Route
RFR ($/TEU) Simulation 1 Scale Factor = 1.5



Summary Information	
Workbook Name	spread sheet model.xls
Number of Simulations	2
Number of Iterations	1000
Number of Inputs	25
Number of Outputs	5
Sampling Type	Latin Hypercube
Simulation Start Time	07/09/2004 13:15
Simulation Stop Time	07/09/2004 13:16
Simulation Duration	00:00:06
Random Seed	1210208572

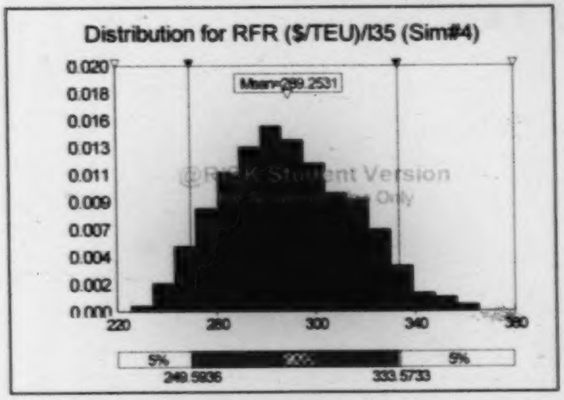


Statistic	Value	%tile	Value
Minimum	241.604128	5%	287.446991
Maximum	427.8261414	10%	295.1997375
Mean	334.5160542	15%	301.4428101
Std Dev	30.45853258	20%	306.9273987
Variance	927.7831255	25%	311.940918
Skewness	0.144966342	30%	316.6962891
Kurtosis	2.726140514	35%	321.7188416
Median	333.8440247	40%	326.1994934
Mode	323.9760437	45%	329.7244568
Left X	287.446991	50%	333.8440247
Left P	5%	55%	338.805542
Right X	386.0704041	60%	341.9080811
Right P	95%	65%	345.9116211
Diff X	98.62341309	70%	350.9829407
Diff P	90%	75%	355.8222656
#Errors	0	80%	360.6520996
Filter Min		85%	365.7171021
Filter Max		90%	374.0029297
#Filtered	0	95%	386.0704041

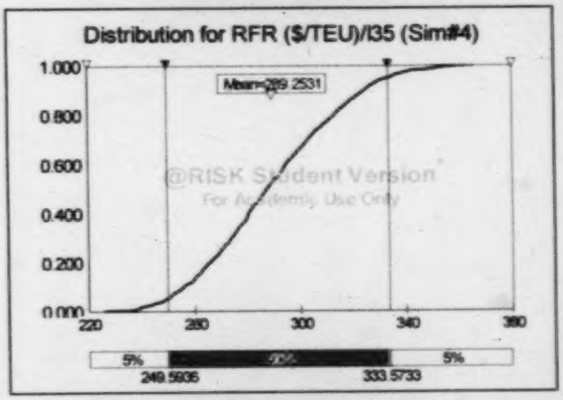


Sensitivity			
Rank	Name	Regr	Corr
#1	New_ Building _P	0.750	0.783
#2	Interest_rate(i) / $	0.385	0.388
#3	Price_bunker($/T(	0.341	0.350
#4	Power Demand_	0.267	0.241
#5	Round trip / C	-0.146	-0.110
#6	Power Demand_(	0.097	0.125
#7	Specific_fuel_cor	0.082	0.129
#8	Steel_Work_cost	0.022	0.149
#9	P&I_Premium($)	0.017	0.160
#10	Age_ship(n) / I	-0.012	-0.036
#11	Drydock_cost / $I	0.012	0.488
#12	Distance / C4	0.000	0.050
#13	Repair_days / $H	0.000	0.043
#14	Management_fee	0.000	0.138
#15	Specific_fuel_cor	0.000	-0.027
#16	H&M_Premium($	0.000	0.582

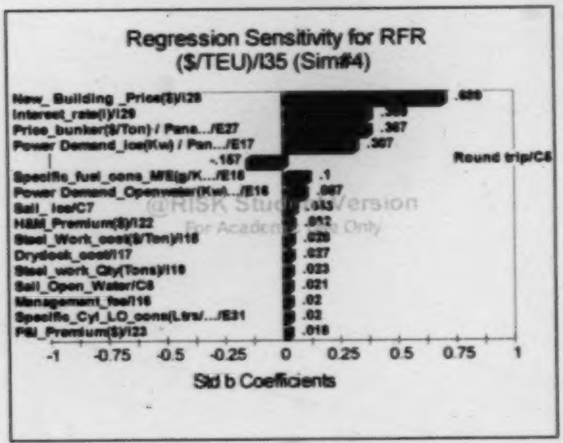
Simulation Results for Yok - St John's Arctic
RFR ($/TEU) / I35 / Simulation 4 Scaling 1.4


Distribution for RFR ($/TEU)/I35 (Sim#4)

Summary Information	
Workbook Name	spread sheet model.xls
Number of Simulations	4
Number of Iterations	1000
Number of Inputs	25
Number of Outputs	2
Sampling Type	Latin Hypercube
Simulation Start Time	07/09/2004 15:38
Simulation Stop Time	07/09/2004 15:38
Simulation Duration	00:00:10
Random Seed	1679086392

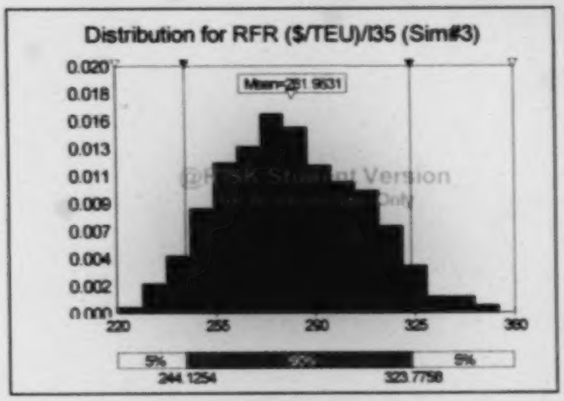

Distribution for RFR ($/TEU)/I35 (Sim#4)

Statistic	Value	%tile	Value
Minimum	225.4929199	5%	249.5936127
Maximum	365.9414063	10%	255.7229156
Mean	289.2530478	15%	261.3849487
Std Dev	26.02281224	20%	265.6304932
Variance	677.186757	25%	269.7094116
Skewness	0.228918887	30%	273.7501526
Kurtosis	2.560943063	35%	277.3996887
Median	287.4562988	40%	280.4937439
Mode	280.6475433	45%	284.1564026
Left X	249.5936127	50%	287.4562988
Left P	5%	55%	291.5783997
Right X	333.5733032	60%	294.7301025
Right P	95%	65%	298.8180847
Diff X	83.97969055	70%	303.1467896
Diff P	90%	75%	307.6930542
#Errors	0	80%	312.9882507
Filter Min		85%	318.1943054
Filter Max		90%	324.533905
#Filtered	0	95%	333.5733032

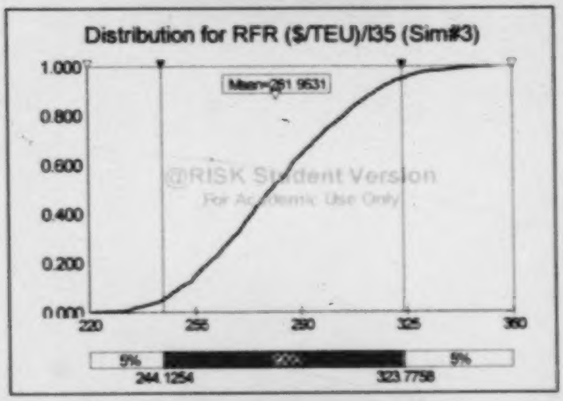

Regression Sensitivity for RFR ($/TEU)/I35 (Sim#4)

Rank	Name	Regr	Corr
#1	New_ Building _P	0.728	0.755
#2	Interest_rate(i) / $	0.365	0.370
#3	Price_bunker($/T	0.364	0.426
#4	Power Demand_i	0.305	0.310
#5	Round trip / C5	-0.155	-0.155
#6	Specific_fuel_con	0.095	0.074
#7	Steel_Work_cost	0.023	0.064
#8	Management_fee	0.020	0.131
#9	Steel_work_Qty(T	0.019	0.036
#10	Specific_Cyl_LO_	0.017	0.107
#11	Resource Utilisati	0.013	0.052
#12	P&I_Premium($)	0.011	0.130
#13	Distance / C4	0.000	-0.034
#14	Drydock_cost / $I	0.000	0.475
#15	H&M_Premium($	0.000	0.556
#16	Unit_Price_Luboi	0.000	-0.037

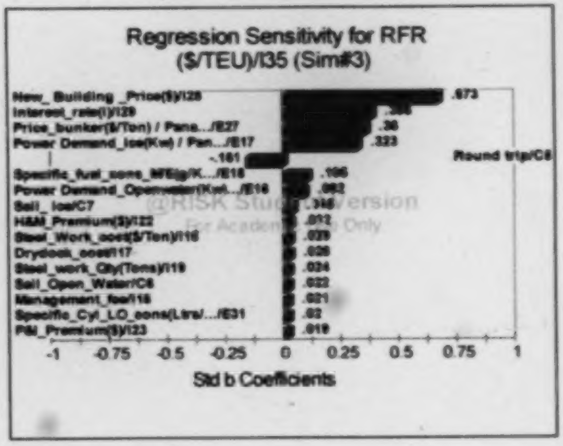
Simulation Results for Yok-St John's Arctic
RFR ($/TEU) / I35 / Simulation 3 Scaling 1.3



Summary Information	
Workbook Name	spread sheet model.xls
Number of Simulations	4
Number of Iterations	1000
Number of Inputs	25
Number of Outputs	2
Sampling Type	Latin Hypercube
Simulation Start Time	07/09/2004 15:38
Simulation Stop Time	07/09/2004 15:38
Simulation Duration	00:00:10
Random Seed	1679086392

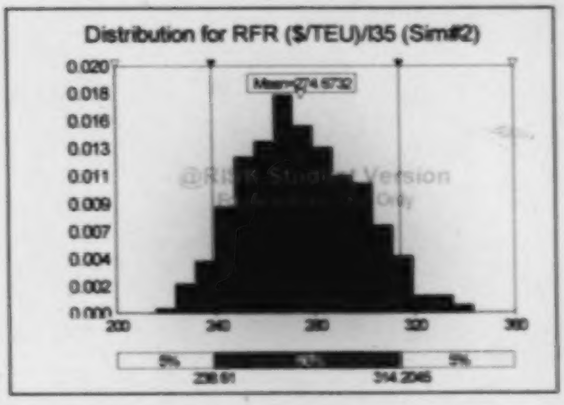


Summary Statistics			
Statistic	Value	%tile	Value
Minimum	220.5749817	5%	244.1253815
Maximum	354.8512268	10%	249.8108215
Mean	281.9631143	15%	255.1684265
Std Dev	24.75408389	20%	259.5128174
Variance	612.7646691	25%	263.5877991
Skewness	0.222836265	30%	267.3053894
Kurtosis	2.569656871	35%	270.9602966
Median	280.5174255	40%	273.8314514
Mode	286.8996277	45%	276.8799744
Left X	244.1253815	50%	280.5174255
Left P	5%	55%	284.5143433
Right X	323.7758484	60%	286.9771423
Right P	95%	65%	290.9538879
Diff X	79.65046692	70%	295.1262817
Diff P	90%	75%	299.5781555
#Errors	0	80%	304.489176
Filter Min		85%	309.264801
Filter Max		90%	315.2911987
#Filtered	0	95%	323.7758484

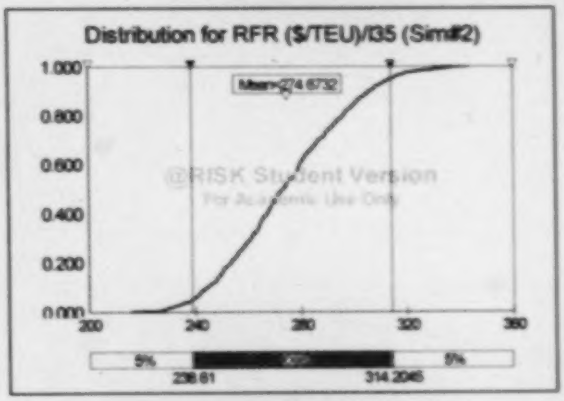


Sensitivity			
Rank	Name	Regr	Corr
#1	New_ Building _P	0.713	0.740
#2	Price_bunker($/T	0.382	0.444
#3	Interest_rate(i) / $	0.356	0.362
#4	Power Demand_	0.321	0.325
#5	Round trip / C	-0.159	-0.158
#6	Specific_fuel_co	0.100	0.079
#7	Steel_Work_cost	0.025	0.065
#8	Management_fee	0.021	0.129
#9	Steel_work_Qty(	0.020	0.030
#10	Specific_Cyl_LO_	0.018	0.107
#11	Resource Utilisat	0.014	0.051
#12	P&I_Premium($)	0.011	0.128
#13	Distance / C4	0.000	-0.035
#14	Drydock_cost / $I	0.000	0.468
#15	H&M_Premium($	0.000	0.544
#16	Unit_Price_Lubo	0.000	-0.039

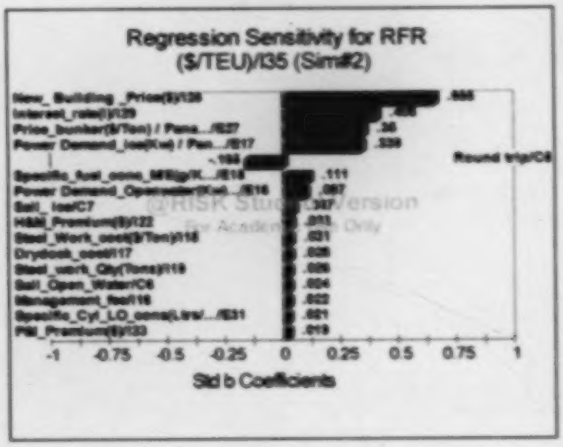
Simulation Results for Yok- St John's Arctic
RFR ($/TEU) / I35 / Simulation 2 Scaling 1.2



Summary Information	
Workbook Name	spread sheet model.xls
Number of Simulations	4
Number of Iterations	1000
Number of Inputs	25
Number of Outputs	2
Sampling Type	Latin Hypercube
Simulation Start Time	07/09/2004 15:38
Simulation Stop Time	07/09/2004 15:38
Simulation Duration	00:00:10
Random Seed	1679086382

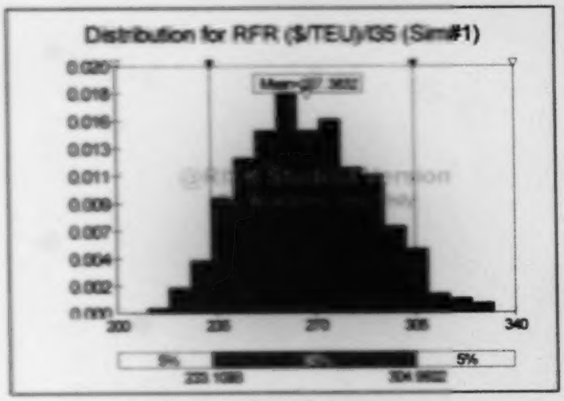


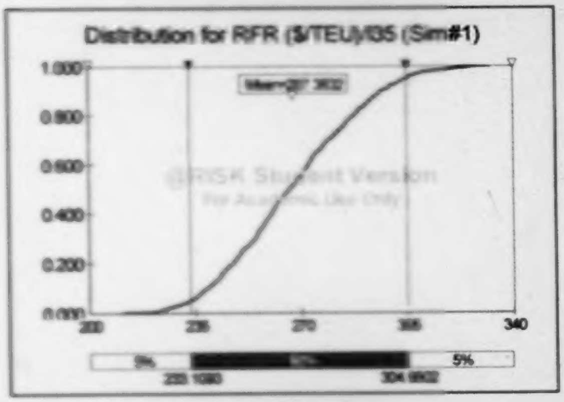
Summary Statistics			
Statistic	Value	%tile	Value
Minimum	215.5251485	5%	238.6100006
Maximum	343.7911682	10%	244.3444519
Mean	274.6731803	15%	249.4208575
Std Dev	23.51150373	20%	253.5280609
Variance	552.7908075	25%	257.1210838
Skewness	0.2181323271	30%	261.1155701
Kurtosis	2.577410141	35%	264.1975708
Median	273.2793579	40%	267.1691284
Mode	279.1446533	45%	269.6515198
Left X	238.6100006	50%	273.2793579
Left P	5%	55%	277.1319275
Right X	314.2044678	60%	279.7380137
Right P	95%	65%	283.0171509
Diff X	75.59446716	70%	287.2153831
Diff P	90%	75%	291.5043945
#Errors	0	80%	296.2210388
Filter Min		85%	300.6242371
Filter Max		90%	305.8742371
#Filtered	0	95%	314.2044678

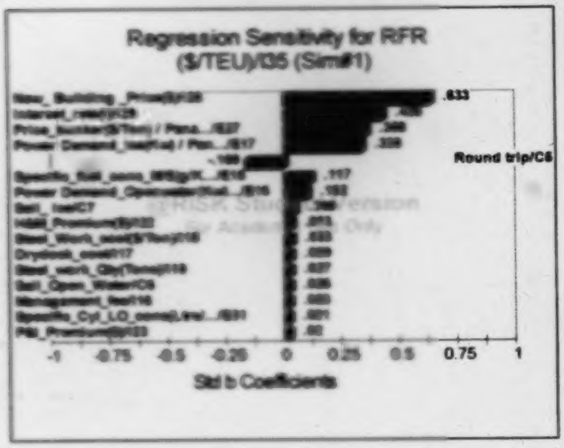


Sensitivity			
Rank	Name	Regr	Corr
#1	New_ Building _P	0.686	0.722
#2	Price_bunker($/T	0.402	0.465
#3	Interest_rate(i) / $	0.346	0.354
#4	Power Demand_i	0.338	0.342
#5	Round trip / C	-0.163	-0.162
#6	Specific_fuel_con	0.106	0.085
#7	Steel_Work_cost	0.026	0.066
#8	Management_fee	0.021	0.128
#9	Steel_work_Qty(T	0.021	0.043
#10	Specific_Cyl_LO_	0.019	0.107
#11	Resource Utilisati	0.015	0.048
#12	P&I_Premium($)	0.012	0.125
#13	Distance / C4	0.000	-0.038
#14	Drydock_cost / $I	0.000	0.459
#15	H&M_Premium($	0.000	0.528
#16	Unit_Price_Lubel	0.000	-0.040

Simulation Results for Yok - St John's Arctic
RFR ($/TEU) / I35 / Simulation 1 Scaling Factor 1.1





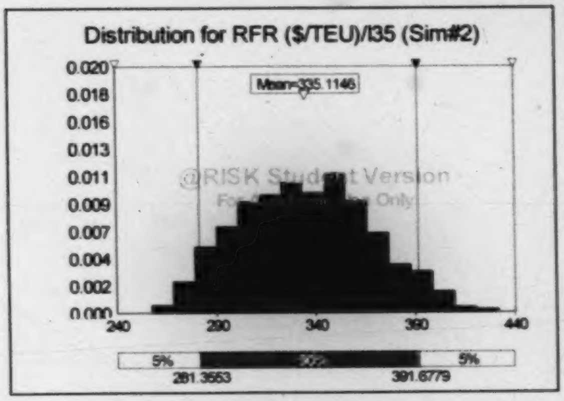


Summary Information	
Workbook Name	spread sheet model.xls
Number of Simulations	4
Number of Iterations	1000
Number of Inputs	25
Number of Outputs	2
Sampling Type	Latin Hypercube
Simulation Start Time	07/09/2004 15:38
Simulation Stop Time	07/09/2004 15:38
Simulation Duration	00:00:10
Random Seed	1679086392

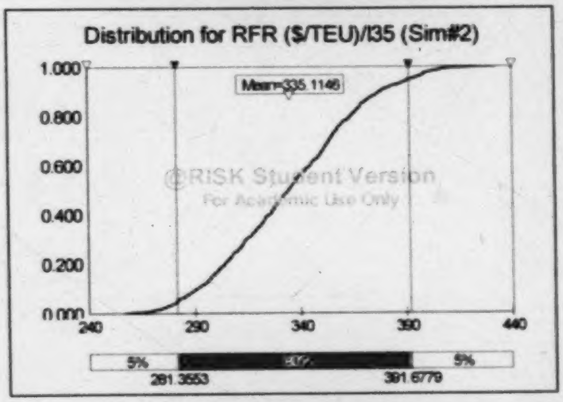
Summary Statistics			
Statistic	Value	%tile	Value
Minimum	210.4753113	5%	233.109314
Maximum	332.9200134	10%	238.6493378
Mean	267.3832467	15%	243.2063446
Std Dev	22.29944305	20%	247.2321167
Variance	497.2651602	25%	250.5545349
Skewness	0.20881968	30%	254.9420776
Kurtosis	2.583549146	35%	257.5060425
Median	266.2153015	40%	260.2320862
Mode	260.9942688	45%	262.754303
Left X	233.109314	50%	266.2153015
Left P	5%	55%	269.6047668
Right X	304.9501648	60%	272.5293274
Right P	95%	65%	275.1808167
Diff X	71.84085083	70%	279.0643616
Diff P	90%	75%	283.7014771
#Errors	0	80%	287.5176392
Filter Min		85%	292.1104736
Filter Max		90%	296.7878418
#Filtered	0	95%	304.9501648

Sensitivity			
Rank	Name	Regr	Corr
#1	New_ Building _P	0.674	0.700
#2	Price_bunker($/T	0.424	0.488
#3	Power Demand_	0.356	0.362
#4	Interest_rate(i) / $	0.334	0.345
#5	Round trip / C5	-0.167	-0.165
#6	Specific_fuel_con	0.111	0.091
#7	Steel_Work_cost	0.028	0.067
#8	Steel_work_Qty(T	0.022	0.048
#9	Management_fee	0.022	0.126
#10	Specific_Cyl_LO_	0.020	0.105
#11	Resource Utilisat	0.015	0.046
#12	P&I_Premium($)	0.012	0.122
#13	Distance / C4	0.000	-0.040
#14	Drydock_cost / $	0.000	0.448
#15	H&M_Premium($	0.000	0.511
#16	Unit_Price_Luboil	0.000	-0.043

Simulation Results for RFR ($/TEU) Yokohama St John's Arctic Route
Simulation 2 Scaling factor = 2.0

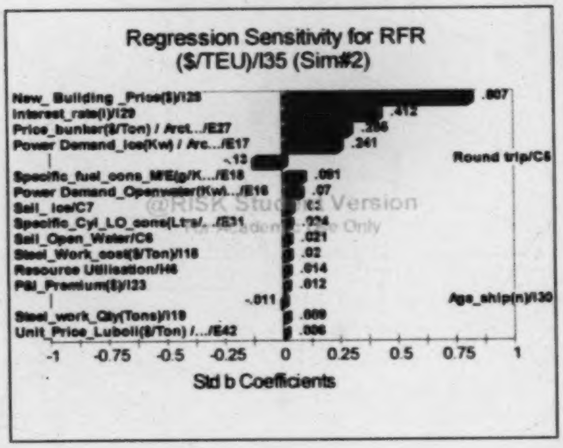


Summary Information	
Workbook Name	spread sheet model.xls
Number of Simulations	2
Number of Iterations	1000
Number of Inputs	25
Number of Outputs	5
Sampling Type	Latin Hypercube
Simulation Start Time	07/09/2004 11:49
Simulation Stop Time	07/09/2004 11:49
Simulation Duration	00:00:05
Random Seed	1878324216



Summary Statistics

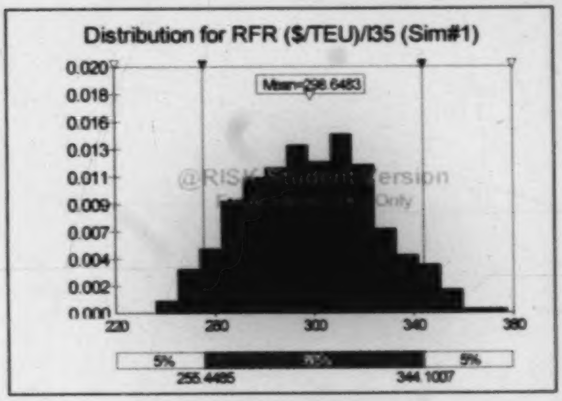
Statistic	Value	%tile	Value
Minimum	257.280304	5%	281.3552551
Maximum	432.3457031	10%	290.9946899
Mean	335.1146215	15%	298.3066711
Std Dev	33.21265224	20%	304.2504883
Variance	1103.080269	25%	309.8275452
Skewness	0.128887138	30%	314.6009216
Kurtosis	2.451564633	35%	320.7060547
Median	334.7722778	40%	325.6039124
Mode	354.2977173	45%	330.0513916
Left X	281.3552551	50%	334.7722778
Left P	5%	55%	338.9502869
Right X	391.677887	60%	344.8393555
Right P	95%	65%	350.2221985
Diff X	110.3226318	70%	354.0882568
Diff P	90%	75%	357.5979919
#Errors	0	80%	364.0823364
Filter Min		85%	369.3143616
Filter Max		90%	378.2688293
#Filtered	0	95%	391.677887



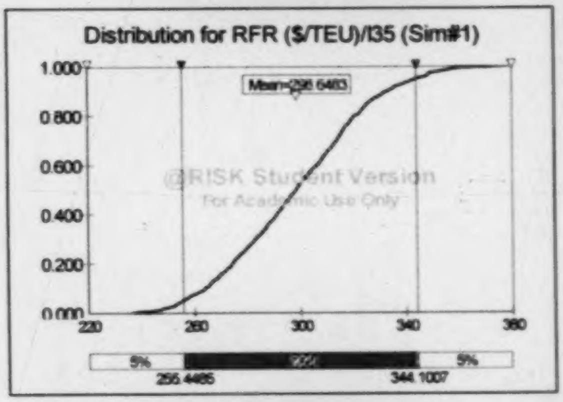
Sensitivity

Rank	Name	Regr	Corr
#1	New_ Building _P	0.802	0.834
#2	interest_rate(i) /	0.410	0.388
#3	Price_bunker($/T	0.288	0.275
#4	Power Demand_	0.242	0.209
#5	Round trip / C5	-0.129	-0.076
#6	Power Demand_	0.067	0.047
#7	Steel_Work_cost	0.023	0.147
#8	Specific_Cyl_LO_	0.020	0.071
#9	P&I_Premium($)	0.012	0.126
#10	Management_fee	0.010	0.141
#11	Resource Utilisat	0.008	-0.057
#12	Time_in_system	0.000	0.076
#13	Port_stay / H7	0.000	-0.062
#14	Repair_days / $H	0.000	0.050
#15	Drydock_cost / $	0.000	0.469
#16	H&M_Premium($	0.000	0.644

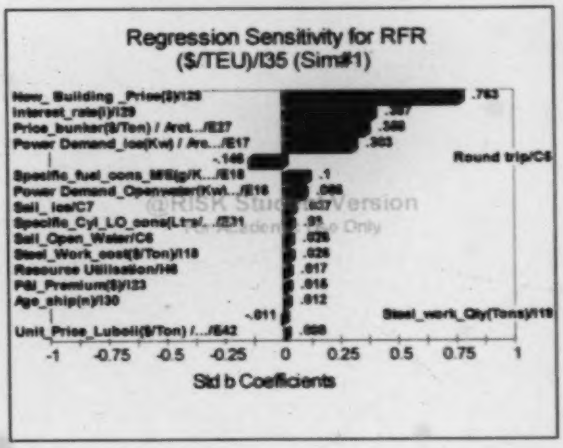
Simulation Results for RFR ($/TEU) Yokohama -St John's Arctic Route
Simulation # 1Scaling factor = 1.5



Summary Information	
Workbook Name	spread sheet model.xls
Number of Simulations	2
Number of Iterations	1000
Number of Inputs	25
Number of Outputs	5
Sampling Type	Latin Hypercube
Simulation Start Time	07/09/2004 11:49
Simulation Stop Time	07/09/2004 11:49
Simulation Duration	00:00:05
Random Seed	1878324216



Summary Statistics			
Statistic	Value	%tile	Value
Minimum	236.0222626	5%	255.4485168
Maximum	377.9568481	10%	263.7539978
Mean	298.6482837	15%	269.0635071
Std Dev	26.54479852	20%	274.2347412
Variance	704.6263285	25%	278.802124
Skewness	0.111736282	30%	282.9484863
Kurtosis	2.532162231	35%	287.5612793
Median	298.5163879	40%	291.0554199
Mode	295.8306702	45%	294.9180603
Left X	255.4485168	50%	298.5163879
Left P	5%	55%	302.0690613
Right X	344.1006775	60%	306.4011841
Right P	95%	65%	310.2429199
Diff X	8[illegible]5216064	70%	313.9393921
Diff P	90%	75%	316.841156
#Errors	0	80%	320.7950745
Filter Min		85%	326.0106506
Filter Max		90%	333.3921814
#Filtered	0	95%	344.1006775



Sensitivity			
Rank	Name	Regr	Corr
#1	New_ Building _P	0.761	0.789
#2	Interest_rate(i) / $	0.387	0.357
#3	Price_bunker($/T	0.357	0.351
#4	Power Demand_I	0.303	0.272
#5	Round trip / C5	-0.147	-0.089
#6	Specific_fuel_con	0.099	0.067
#7	Power Demand_C	0.086	0.065
#8	Specific_Cyl_LO_	0.031	0.069
#9	Steel_Work_cost	0.026	0.143
#10	P&I_Premium($)	0.019	0.117
#11	Management_fee	0.007	0.134
#12	Time_in_system	0.000	0.072
#13	Port_stay / H7	0.000	-0.061
#14	Repair_days / $H	0.000	0.053
#15	Drydock_cost / $I	0.000	0.444
#16	H&M_Premium($	0.000	0.610